Universidade de Lisboa

Faculdade de Medicina Dentária

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Dissertação

Mestrado Integrado em Medicina Dentária

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Dissertação orientada pela Professora Doutora Cristina Bettencourt Neves e co-orientada pelo Professor Doutor Jaime de Almeida Portugal

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Resumo

A estomatite protética ou candidíase atrófica crónica é uma patologia frequentemente presente em indivíduos portadores de próteses removíveis. Não obstante a sua natureza multifactorial, apresenta a infecção por espécies de *Candida*, principalmente *Candida albicans*, como o seu principal factor etiológico. O trauma, a presença de biofilme, o uso ininterrupto de prótese, xerostomia e alterações do pH salivar, são outros factores coadjuvantes e precipitantes. Os polímeros das resinas acrílicas das bases das próteses apresentam-se, à semelhança de células hospedeiras do indivíduo, como local de colonização da *Candida albicans*, constituindo esta, um factor primordial e necessário no desenvolvimento do processo patológico. Posto isto, constata-se que o desenrolar do processo infeccioso é influenciado pelos materiais das bases das próteses, já que estes constituem um meio adequado à aderência de biofilmes.

O tratamento farmacológico desta condição da cavidade oral apresenta-se por vezes ineficaz, dadas as condicionantes existentes, sobretudo a dificuldade de aplicação da dose correcta do fármaco no local da lesão, bem como a dificuldade da sua manutenção na cavidade oral durante o tempo necessário para que o seu potencial terapêutico máximo seja atingido e o seu efeito prevaleça. Neste momento não se encontra padronizado o tempo de aplicação destes fármacos, quer por via tópica quer por via sistémica. Daqui podem resultar efeitos indesejados, na medida em que, as oscilações nos níveis farmacológicos são mais passíveis de se verificarem.

Na tentativa de contornar as problemáticas acima explicitadas, têm vindo a desenvolver-se outros mecanismos de aplicação dos agentes terapêuticos mencionados. De entre estes mecanismos destaca-se a impregnação de dispositivos médicos com agentes antimicrobianos. A esta forma de apresentação tem vindo a ser associado um potencial efeito na prevenção da aderência de microrganismos, daqui resultando uma interferência importante no mecanismo fulcral da infecção. Além desta vantagem, os mesmos dispositivos, ao permitirem a libertação do agente terapêutico no local da infecção, possibilitam que se minimizem os riscos de utilização de doses subterapêuticas ou de doses que conduzam a uma toxicidade sistémica, para além de potencialmente inibirem a manutenção do biofilme.

A clorexidina (CHX) apresenta-se como um agente antimicrobiano de largo espectro, com acção quer bactericida quer bacteriostática, sendo prescrita desde há vários anos em larga escala na prática da medicina dentária. A incorporação da mesma

em resinas acrílicas tem obtido resultados eficazes na diminuição da capacidade da *Candida albicans* em aderir às células epiteliais da cavidade oral, sendo que é libertada com uma taxa de eluição inicial de valor elevado, havendo um processo de libertação controlada subsequente, estendendo-se até aos 28 dias de duração dos estudos existentes.

Relativamente à concentração tida como eficaz no combate à *Candida albicans*, o que se encontra patente nos estudos é um valor de 10% da massa do pó da resina. Contudo sabe-se que esta quantidade de CHX tem influência negativa sobre a microdureza e resistência à flexão das resinas acrílicas nas quais é incorporada, diminuindo os seus valores.

O principal objectivo deste estudo foi avaliar quer os efeitos da resina de rebasamento, incorporada com CHX, nos valores de microdureza e resistência à flexão, quer os efeitos da incorporação de CHX, em várias concentrações, sobre os parâmetros mencionados. Para o devido efeito foram estudadas três resinas acrílicas de rebasamento, sendo duas delas directas, Kooliner, Ufi Gel Hard, e uma indirecta, Probase Cold.

Prepararam-se amostras (64x10x3,3 mm), de cada uma das resinas, recorrendo a moldes rectangulares de aço inoxidável, tendo-se constituído um grupo de controlo, sem incorporação de CHX (0%), e quatro grupos com concentrações do mesmo agente antomicrobiano de 1%, 2,5%, 5% e 7,5% da massa do pó de cada material. Para os testes de microdureza e de resistência à flexão que foram levados a cabo, prepararam-se oito amostras por cada grupo anteriormente referido. Todas as amostras, após preparo, foram mantidas a 37±2ºC durante 48±2 horas, sendo ao fim desse período testadas.

Os resultados da microdureza obtiveram-se recorrendo ao teste de microdureza de Knoop. Após este teste, tinha lugar o de resistência à flexão de três pontos.

Foi realizada a análise descritiva dos valores de microdureza e de resistência à flexão, tendo sido determinados os valores de média, mediana, desvio padrão e máximo e mínimo.

Não apresentando os dados uma distribuição normal para as variáveis em estudo (verificação feita através de testes Kolmogorov-Smirnov), os resultados foram submetidos a testes não-paramétricos de acordo com o método de Kruskal-Wallis, seguindo-se comparações múltiplas utilizando testes Mann-Whitney, com correcções de Bonferroni, para determinar se existiam diferenças específicas significativas entre materiais e grupos de concentrações de CHX. Um valor de significância de 5% foi a

referência em todos os testes estatísticos realizados. Os dados foram analisados com recurso ao software SPSS Statistics (SPSS Inc., Chicago, IL, USA).

No respeitante ao efeito das resinas acrílicas de rebasamento sobre a microdureza, determinaram-se valores diferentes entre grupos (p<0,001). Os espécimes da resina Probase Cold tiveram valores mais elevados que os outros materiais (média=11,58 ±0.41), seguindo-se a Ufi Gel Hard (média=8,91 ±0,87) e Kooliner (média=5,27 ±0,70).

Quanto ao efeito da incorporação de diferentes concentrações de CHX na microdureza, para os espécimes de Kooliner obtiveram-se diferenças entre grupos. O grupo com 1% de CHX teve valores mais elevados que o grupo de 5% de CHX e de 7,5% de CHX. No que diz respeito aos espécimes de Ufi Gel Hard, obtiveram-se igualmente valores diferentes entre grupos. O grupo de 5% de CHX teve valores mais elevados em comparação com o de 0% de CHX e o de 1%. Já para a Probase Cold, não existiram diferenças estatisticamente significativas entre nenhum dos grupos.

Avaliando o efeito da resina de rebasamento sobre a resistência à flexão, compararam-se igualmente os três materiais e verificaram-se diferenças significativas entre grupos.

A resina Probase Cold teve valores mais elevados (média=72,56 ±12,35) que a Kooliner (média=38,89 ±4,60) e a Ufi Gel Hard (média=36,96 ±6,43) que não mostraram diferenças entre si.

No que concerne aos efeitos da incorporação de diferentes concentrações de CHX sobre a resistência à flexão, constatou-se que para os espécimes de Kooliner, nenhum grupo mostrou diferenças no parâmetro mencionado. Para a Ufi Gel Hard, a incorporação de CHX não se fez acompanhar de diferenças significativas nos valores de resistência à flexão.

Em relação à Probase Cold houve diferenças significativas entre grupos, causadas pelos valores do grupo de concentração de CHX de 7,5%, que se apresentaram inferiores quando comparados com o grupo de 0% e 1% de CHX.

O presente estudo permite perceber que as várias concentrações de CHX incorporadas, em geral, não prejudicam as propriedades mecânicas destes materiais, podendo inclusive a incorporação do referido fármaco constituir um factor de melhoria dessas mesmas propriedades, quando em concentrações determinadas.

No presente afiguram-se necessários estudos que permitam determinar o grau de conversão das resinas acrílicas e quantificar a quantidade de monómero residual. São

necessários também, estudos microbiológicos e de citotoxicidade com CHX. Seria igualmente relevante a execução de estudos de microscopia electrónica de varredura e de transmissão, com o intuito de aferir as alterações que ocorrem na rede polimérica das resinas, aquando da inclusão de fármacos nas mesmas. Tudo isto se coloca na perspectiva de que cruzando-se os resultados dos estudos mencionados com os conhecimentos já adquiridos, posteriormente poder-se-iam conduzir investigações clínicas, isto tendo em vista que próteses removíveis com propriedades antimicrobianas constituiriam seguramente uma grande melhoria na saúde oral dos pacientes portadores das mesmas.

Palavras-chave: Resinas acrílicas; Incorporação de fármacos; Microdureza; Resistência à flexão

Abstract

The main goal of this study was to evaluate the effect of chlorhexidine incorporation on the microhardness and flexural strength of three acrylic reline resins, Kooliner, Ufi Gel Hard and Probase Cold.

For each material there were five groups, with different chlorhexidine concentrations (n=8), being the control group the one with 0% chlorhexidine. The other concentrations studied were 1%, 2.5%, 5% and 7.5%. Specimens with 64x10x3.3mm, were tested for Knoop hardness and flexural strength values.

Data were submitted to nonparametric tests according to the Kruskal-Wallis ($p<0.05$).

Concerning the effects of the reline resin on microhardness, comparing all three materials led to the conclusion that microhardness values showed differences between groups, having Probase Cold the higher values, followed by Ufi Gel and Kooliner.

In terms of effects of different chlorhexidine concentrations incorporation on the resins, there were differences between groups on Kooliner and Ufi Gel specimens. No statistically significant differences were found for Probase Cold, between groups of chlorhexidine.

Relatively to effects of the reline resin on flexural strenght, comparing all three materials, there were differences between groups, with Probase Cold showing higher values than the other two materials.

Regarding the effect of incorporation of different concentrations of chlorhexidine on flexural strenght, Kooliner groups didn't show differences between them as well as Ufi Gel. Concerning Probase specimens, there were differences between groups that showed that 7.5% chlorhexidine group had lower values than control and 1% chlorhexidine group.

Globally, it was possible to determine some important aspects of the effects of incorporation of different concentrations of chlorhexidine on the mechanical properties of acrylic reline resins.

Keywords: Acrylic resins; Drug incorporation; Microhardness; Flexural strenght

1. Introduction

It is of our knowledge that the use of a dental prosthesis is very important for a totally or partially edentulous patient as it can give him back function, esthetic and psychological well-being (Gunjan Dhir *et al*., 2007). These removable appliances, besides the previously mentioned advantages, are simple to fabricate, versatile, permit modifications along time, have good mechanical properties (Gunjan Dhir *et al*., 2007) and moreover they are fairly easy to maintain (Tawse-Smith *et al*., 2001). However they are susceptible to microbial adhesion (Gunjan Dhir *et al*., 2007). This tendency for adherence of pathogenic microorganisms can be stronger due to acrylic resins' intrinsic porous nature and their surface deterioration, derived from hygiene procedures and food and mastication manifestations (Brozek *et al*., 2007; Brozek *et al*., 2008; Brozek *et al*., 2011) and resulting on increased roughness and creation of irregularities. For these reasons it is know that denture bases may act as reservoirs of microorganisms, which in turn may contribute to oral diseases (Wilson J., 1998; Lamfon H. *et al*, 2005; Fernandes R.A. *et al*., 2007; Casemiro L.A. *et al*., 2008).

Denture induced stomatitis or chronic atrophic candidiasis is the most common infection affecting mostly the palatal mucosa, being highly prevalent in denture wearers (Moskona D. *et al*., 1992; Reichart P.A., 2000). This pathological entity is characterized by inflammation of oral tissues and despite its multifactorial nature, regardless of the precipitating mechanism, is characterized by the presence of a yeast biofilm, associated to the base of the prosthesis, being mainly constituted by *Candida* species, mainly *Candida albicans* (Bastiann R.J., 1976; Olsen and Birkeland, 1977; Budzt-Jorgensen E., 1978; Monsenego P., 2000; Nikawa H. *et al*., 2003; Vanden A. *et al*., 2008; Boscato N. *et al*., 2009).

The treatment of this disease is complex. Traditionally it consists of antifungal drugs prescription or modification of the prosthetic appliance to receive a temporary soft tissue reliner. There are some inherent problems with these treatment modalities. Antimycotic agents are helpful, however, recurrence of stomatitis tends to be quick unless dentures' surface is modified to eliminate *Candida* hyphae (Kulak Y. *et al*., 1994), as even when hygiene solutions are used for denture cleaning, *Candida* tends to subsist (Nikawa H. *et al*., 2003; Boscato N. *et al*., 2009). Moreover, as this pathological condition is relatively painless, it's hard to have patients' compliance regarding the therapeutic regimen, therefore diminishing the probabilities of treatment success.

Given these problems, there has been, over the years, a tendency leading to the use of dental materials, namely denture liners and resin itself, as carriers of antimicrobial agents (Douglas W.H., 1977; Mirth D.B., 1989; Scnheid T.R., 1992; Ahlström *et al*., 1999; Batoni G. *et al*., 2001; Etienne O. *et al*., 2005; Hiraishi *et al.*, 2008; Redding *et al.*, 2009; Cao Z. *et al*., 2010; Acosta-Torres *et al.*, 2012; Cochis *et al.*, 2012; King G., 2012; Marra *et al.*, 2012; Shinonaga *et al*., 2012; Salim *et al*., 2012a; Salim *et al*., 2012c; Salim *et al*., 2013a; Sousa C, 2014).

Chlorhexidine (CHX) has been studied regarding its use on resin acrylics (Addy M. and Handley R., 1981; Thaw M. *et al*., 1981; Riggs P.D. *et al*., 2000; Wyre R.M. and Downes S., 2000; Patel M.P. *et al*., 2001; Salim *et al*., 2012a; Salim *et al*., 2012b; Salim *et al*., 2013a; Alaa Al-Haddad *et al*., 2014; Martinna M.B. *et al*., 2014; Sousa C., 2014). It is as an antimicrobial agent, which is active against a large number of microorganisms, where *Candida* is included. It has been showed that once drugs like Fluconazole and CHX are incorporated into PMMA, they retain their therapeutic dose for up to 28 days (Vanden A. *et al*., 2008; Boscato N. *et al*., 2009; Pusareti C.R. *et al*., 2009; Cao Z. *et al*., 2010) with CHX having better results both on releasing and microbiological tests (Lamfon *et al*., 2004; Amin *et al*., 2009; Pusateri C.R. *et al*., 2009; Redding S. *et al*., 2009; Ryalat *et al*., 2011; Salim *et al*., 2012b; Salim *et al*., 2013a; Salim *et al*., 2013b). Only one study by Sousa (Sousa C., 2014) evaluated the effect of CHX incorporation on the mechanical and surface properties of acrylic reline resins after CHX has been completely eluted from these materials. On the referred study, an aging thermocycling process, corresponding to 3 months of temperature variation in the oral environment (Gale and Darvell, 1999), which can be induced by breathing, eating and drinking (Palmer *et al*., 1992), was applied. This 3 months period was chosen because there weren't found studies where had been established when CHX had completely vanished from the acrylic resin. Therefore, this time interval was considered to be an approximation of the time after which it was expected that CHX had been completely eluted from the resin (Sousa C., 2014).

When incorporated in acrylic resins, 10% (*w/w*) CHX concentration showed to be the most effective against *Candida albicans* (Amin *et al.*, 2009; Ryalat *et al.*, 2011; Salim *et al.*, 2012a; Salim *et al.*, 2013b). However there are still some uncertainties regarding the effects of these materials' incorporation techniques on the mechanical properties of acrylic resins (Addy M. and Handley R., 1981; Thaw M. *et al*. 1981) and other problems can arise due to release of antimicrobial substances from the resins, such

as toxic effects on the oral mucosa and loss of effectiveness over time (Imazato S. *et al*., 1994; Pesci-Bardon C. *et al*., 2006;). In order to attempt to fill this gap in the literature, Sousa (Sousa C, 2014) and Martinna (Martinna M.B. *et al*.,2014) tested the effects of 10% CHX incorporation on acrylic reline resins. Both studies showed the negative influence of such concentration of CHX on the resins mechanical properties.

Armed with this knowledge, and studying three different acrylic reline resins, the present study had two main goals: determine the effects of the reline resin type on microhardness and flexural strenght and determine the effects of the incorporation of different CHX concentrations over the same parameters.

2. Objectives

The objective of this study was to evaluate the effects of different percentages of CHX incorporation on the microhardness and flexural strenght of three acrylic reline resins, according to the following hypotheses:

H0: The resin type doesn't influence the microhardness.
H1: The resin type influences the microhardness.

H0: The microhardness isn't affected by the different concentrations of CHX incorporated.
H1: The microhardness is affected by the different concentrations of CHX incorporated.

H0: The resin type doesn't influence the flexural strength
H1: The resin type influences the flexural strength.

H0: The flexural strenght isn't affected by the different concentrations of CHX incorporated.
H1: The flexural strenght is affected by the different concentrations of CHX incorporated.

3. Materials and Methods

In the present study, three auto-polymerizing acrylic resins (Table 3.1), which are presented in a liquid-powder formulation, were chosen because of their differences in terms of chemical composition. Two of these resins are direct reline resins: Kooliner (GC America Inc, Alsip, Illinois, USA) (Figure 3.1a), a non-crosslinking material, and Ufi Gel Hard (Voco GmbH, Cuxhaven, Germany) (Figure 3.1b), a cross linking material, composed of pre-polymerized poly(ethyl methacrylate) (PEMA) powder particles and the monomers isobutylmethacrylate (IBMA) or 1,6-hexanodioldimethacrylate (1,6-HDMA), respectively. The other resin is an indirect reline resin, Probase Cold (Ivoclar Vivadent AG, Liechenstein) (Figure 3.1c), a poly(methyl methacrylate) (PMMA) based material which has methylmethacrylate (MMA) as monomer (Arima *et al*., 1995 and 1996).

Table 3.1- Materials under evaluation in the study

Product	Manufacturer	Batch number	P/L ratio (g/mL)	Composition	Curing cycle
Kooliner (K)	GC America Inc., Alsip, Illinois, USA	1406232(P) 1404241(L)	1.4/l	**P**: PEMA **L**: IBMA	10 minutes 37ºC
Ufi Gel Hard (U)	Voco GmbH, Cuxhaven, Germany	1438417(P) 1443063(L)	1.77/l	**P**: PEMA **L**: HDMA	7 minutes 37ºC
Probase Cold (PC)	Ivoclar Vivadent AG, Liechtenstein	S41038(P) U03356(L)	1.5/l	**P**: PMMA **L**: MMA	15 minutes 40ºC 2-4 bar

P- Powder, L- Liquid, PEMA- polyethyl methacrylate, IBMA- isobutyl methacrylate, HDMA- hexanediol dimethacrylate, PMMA- polymethyl methacrylate, MMA- methyl methacrylate

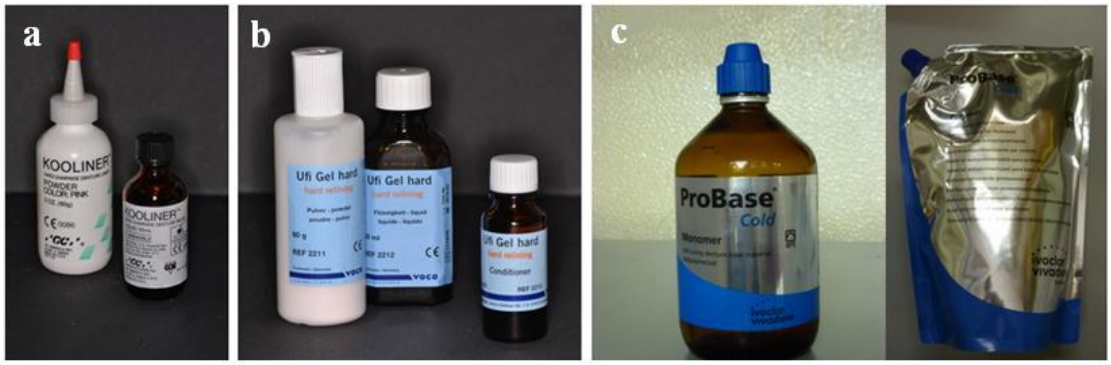

Figure 3.1- Materials under evaluation in the present study: a) Kooliner; b) Ufi Gel Hard; c) Probase Cold.

3.1 Preparation of the specimens

The acrylic resins were manipulated according to the manufacturer's instructions (Table 3.1). The liquid was measured using a pipette and the powder was weighed using a precision scale (Mettler Toledo). On the experimental specimens, chlorhexidine diacetate monohydrate (Panreac Applichem, Darmstad, Germany) (CHX) (Figure 3.2a) at proportions of 1%, 2.5%, 5% and 7.5% of the acrylic resins' powder weight (w/w) was incorporated and mixed using a mortar and pestle for homogenization (Figure 3.2b).

As ISO 20795-1 recommends (ISO 20795-1: 2013), rectangular shaped stainless steel molds were used to prepare specimens of each material. In order to simulate the intraoral polymerization of direct reline resins, the materials dough was maintained under compression at 37±2ºC, during the recommended polymerization time (Table 3.1). Polymerization of the indirect reline resin was carried out in a pressure device (Ivomat Ivoclar Vivadent, Liechenstein) (Figure 3.3) at recommended temperature, time and pressure (Table 3.1).

Figure 3.2- a) Chlorhexidine diacetate monohydrate; b) Incorporation and homogenization on the resin

Figure 3.3- Ivomat pressure device

3.2 Microhardness and Flexural Strength tests

Forty samples (64x10x3.3 mm) of each material were prepared. There were five groups (n=8) with different CHX percentages incorporated in specimens, being the control group the one in which the CHX percentage was zero (Table 3.2). On each preparation, the stainless steel mold was placed on a glass plate covered by a polyester sheet. The materials' doughs were prepared and placed into the mold. Another polyester sheet and glass were positioned on top of the mold and the set was maintained under compression (Figure 3.4). After polymerization the samples were removed from the molds and all edges of each sample were polished with a 600-grit silicon carbide paper (Carbimate Paper Discs, Buehler Ltd, Lake Bluff, IL), by a polisher with constant refrigeration (Figure 3.5). Both experimental and control specimens were kept at 37ºC±2ºC for 48±2h before testing (ISO 20795-1: 2013).

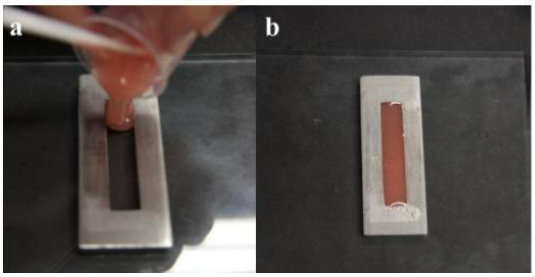

Figure 3.4- Preparation of the specimens; a) Mixture of liquid and powder formulations is placed in the stainless steel mold; b) Mixture and mold between polyester sheets and glass plates

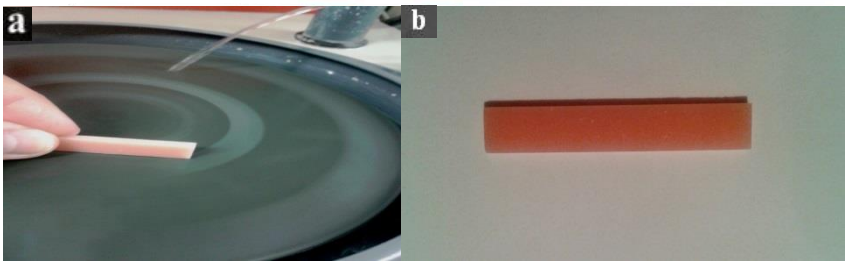

Figure 3.5- Preparation of the specimens. After polymerization and removal of the specimen from the molds; a) Irregularities were removed; b) Example of polymerized Probase Cold specimen

Table 3.2- Schematization of distribution of the specimens

Material	CHX incorporation percentage
Kooliner (K)	CHX 0% (*n*=8) CHX 1% (*n*=8) CHX 2.5% (*n*=8) CHX 5% (*n*=8) CHX 7.5% (*n*=8)
Ufi Gel Hard (U)	CHX 0% (*n*=8) CHX 1% (*n*=8) CHX 2.5% (*n*=8) CHX 5% (*n*=8) CHX 7.5% (*n*=8)
Probase Cold (PC)	CHX 0% (*n*=8) CHX 1% (*n*=8) CHX 2.5% (*n*=8) CHX 5% (*n*=8) CHX 7.5% (*n*=8)

3.2.1 Knoop Hardness Test

The microhardness of all the specimens was obtained using a microhardness indention machine (Duramin, Struers DK 2750, Balleruo, Denmark), with a Knoop diamond indentor, with an elongated pyramid's shape (Figure 3.6). The microhardness test parameters were 98.12 mN load during 30 seconds (Pinto Lde *et al*., 2010).

Using the Duramin software, the length of the pyramidal indentations was immediately measured by the operator, after each indentation, on a maximum period of ten seconds. As there was a short time interval between indentation and measurement, it was assumed that the viscoelastic recovery was minimal.

The conversion of these measurements into Knoop hardness numbers (KHN-kg/mm^2) was made automatically by the equipment. Twelve measurements were made in each sample.

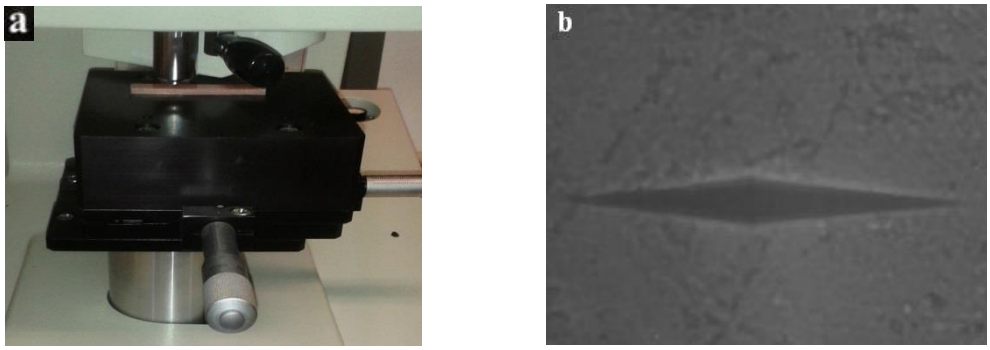

Figure 3.6- a) Knoop indentor in a microhardness machine; b) Microscopic image of a Knoop indention on an Ufi Gel Hard specimen

3.2.2 Flexural strength test

After microhardness test was carried out, all specimens were submitted to the flexural strength test, in a servo-hydraulic universal machine (Instron Model 4502) (Figure 3.7) using three point loading. First the specimen's dimensions (width and thickness) were measured using a digital micrometer (Mitutoyo Digimatic, MFG. Co., Ltd Tokyo, Japan), of 0.01mm precision, and their averages were introduced in the software just before testing. A crosshead speed of 5mm per minute was used and the distance between supports was 50mm, as described elsewhere (ISO 20795-1: 2013).

Load was applied until failure and the fracture load was recorded in Newtons (N). The flexural strength was expressed in megapascal (MPa) and calculated using the formula:

$$FS = \frac{3Wl}{2bd^2}$$

Where *FS* is the flexural strength, *W* is the maximum load before fracture (N), *l* is the distance between supports (50mm), *b* is the specimen's width (mm) and *d* is the specimen's thickness (mm).

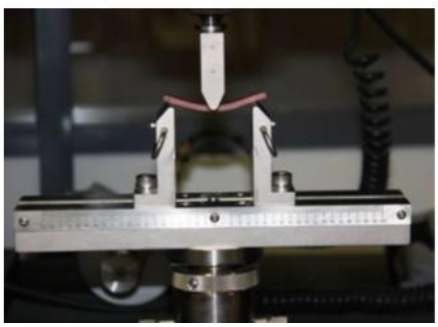

Figure 3.7- Specimen being submitted to 3 point flexural strenght test in an universal machine

3.3 Statistical analysis

Descriptive statistics of microhardness and flexural strength was carried out. Mean, median, standard deviation and maximum and minimum values were determined.

Since data did not follow a normal distribution for the studied variables (verified by Kolmogorov-Smirnov normality tests), the results were submitted to the nonparametric tests according to the Kruskal-Wallis method, followed by multiple comparisons using Mann-Whitney tests with Bonferroni corrections to determine whether there were specific significant differences among materials and groups.

In all statistical tests, it was considered the 5% level of significance ($p<0.05$).

Data were statistically analyzed using SPSS Statistics 20 (SPSS Inc., Chicago, IL, USA).

4. Results

For each material, the descriptive analysis of the data was carried out, including mean, median, standard deviation and maximum and minimum values for microhardness (Appendix 1, Table 1) and flexural strength (Appendix 1, Table 2).

4.1 Effect of the reline resin on microhardness

Mean and standard deviation of microhardness values of the different materials are graphically presented (Figure 4.1).

Comparing all three materials (Figure 4.1), the microhardness values showed differences between the groups (p<0.001).

Probase Cold showed higher values than the other groups (mean=11.58 ±0.41), followed by Ufi Gel Hard (mean=8.91 ±0.87) and Kooliner (mean=5.27 ±0.70).

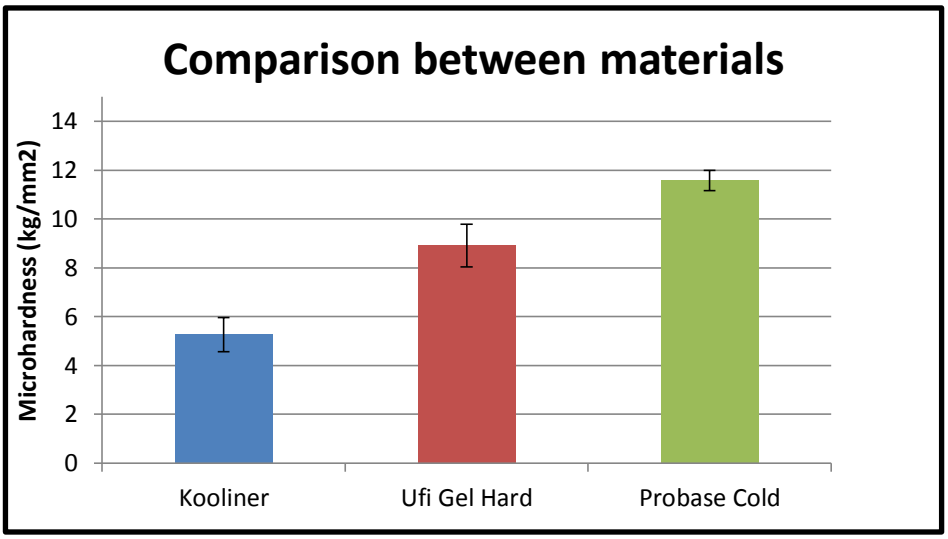

Figure 4.1 – Mean and standard deviation of values of microhardness (kg/mm^2) of Kooliner, Ufi Gel Hard and Probase Cold.

4.2 Effect of CHX incorporation on microhardness

Mean and standard deviation of the values are graphically present and explained by material (Figures 4.2-4.4).

For Kooliner specimens (Figure 4.2), there were differences between different groups (p=0.001). The 1% CHX group showed higher values than the 5% CHX group (p=0.02) and the 7.5% CHX group (p=0.025) groups.

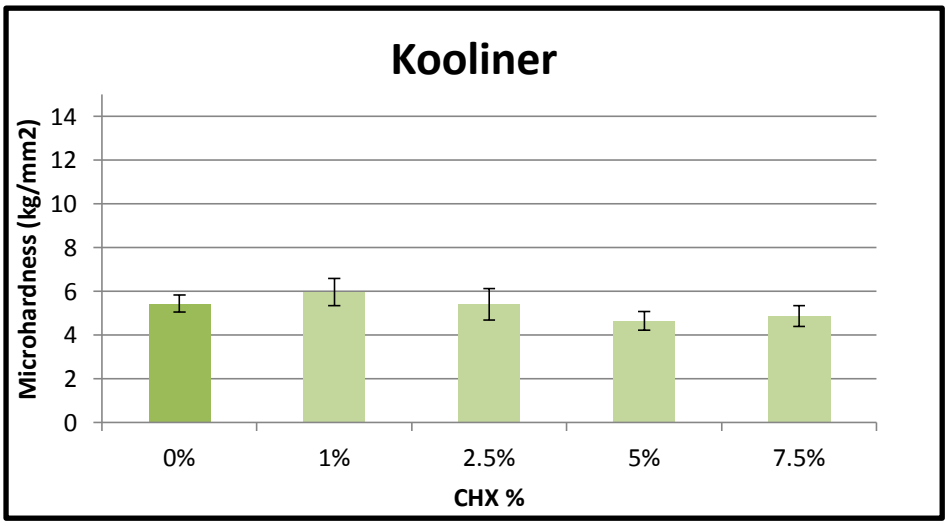

Figure 4.2- Mean and standard deviation of values of microhardness (kg/mm^2) of Kooliner.

Ufi Gel Hard specimens (Figure 4.3) showed differences between groups (p= 0.004). The 5% CHX group showed higher values comparing to 0% (p=0.032) and 1% (p=0.012).

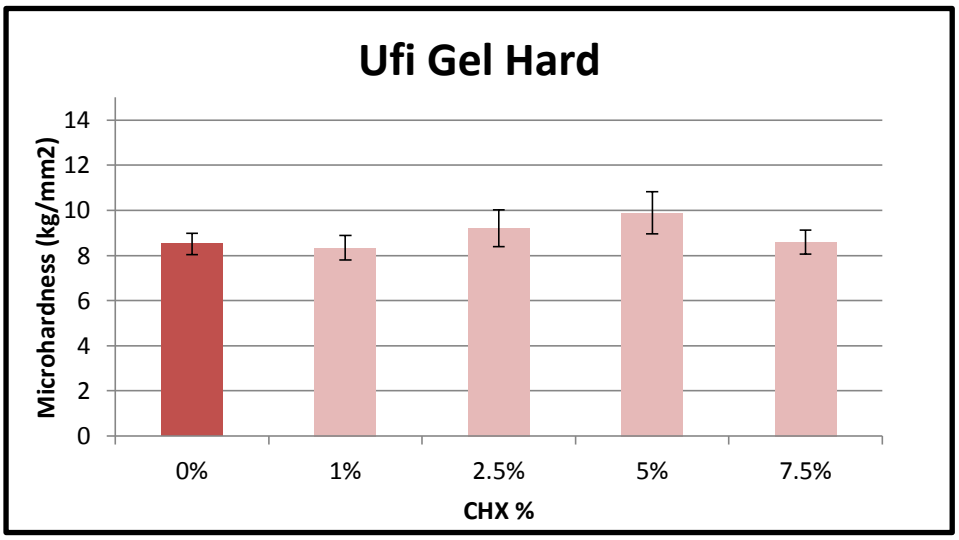

Figure 4.3- Mean and standard deviation of values of microhardness (kg/mm^2) of Ufi Gel Hard.

Concerning Probase Cold, there were no statistically significant differences between any of the groups of CHX concentrations (p>0.05).

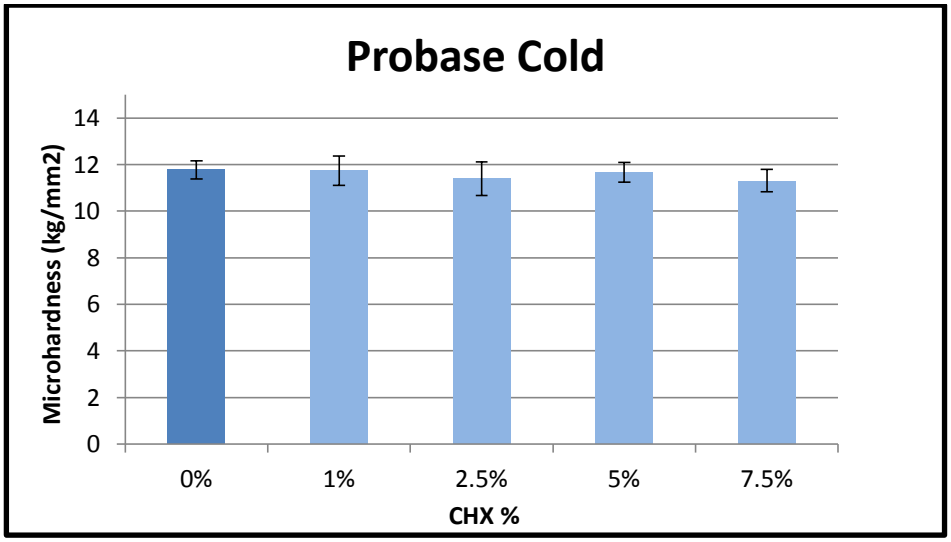

Figure 4.4- Mean and standard deviation of values of microhardness (kg/mm^2) of Probase Cold.

4.3 Effect of the reline resin on flexural strenght

Mean and standard deviation of flexural strenght values of the different materials are graphically presented (Figure 4.5).

Comparing all three materials (Figure 4.5), there was statistically significant differences between groups (p<0.001).

Probase Cold group showed higher levels (mean=72.56 ±12.35) compared to Kooliner (mean=38.88 ±4.60) and Ufi Gel Hard (mean=36.96 ±6.43) groups. –These last two materials didn't show differences between them (p=0.746).

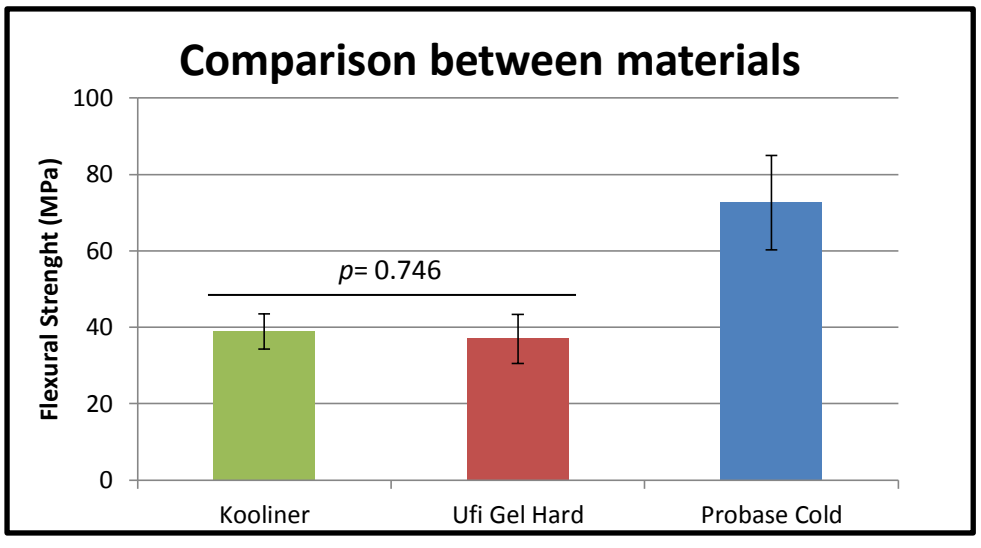

Figure 4.5 – Mean and standard deviation of values of flexural strenght (MPa) of Kooliner, Ufi Gel Hard and Probase Cold. Lines above groups showed no statistically significant differences.

4.4 Effect of CHX incorporation on flexural strength

Mean and standard deviation are graphically presented and explained by material (Figures 4.6-4.8).

Regarding Kooliner specimens (Figure 4.6), all groups didn't show differences in flexural strenght values (p=0.120).

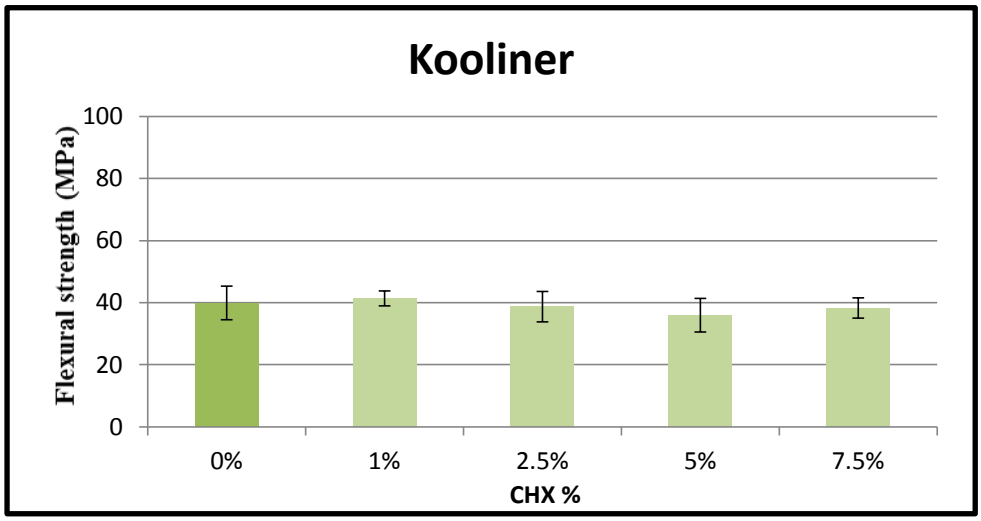

Figure 4.6 – Mean and standard deviation of values of flexural strength (MPa) of Kooliner.

For Ufi Gel Hard specimens (Figure 4.7), the incorporation of different concentrations of CHX made no significant changes on the flexural strengths values (p=0.098).

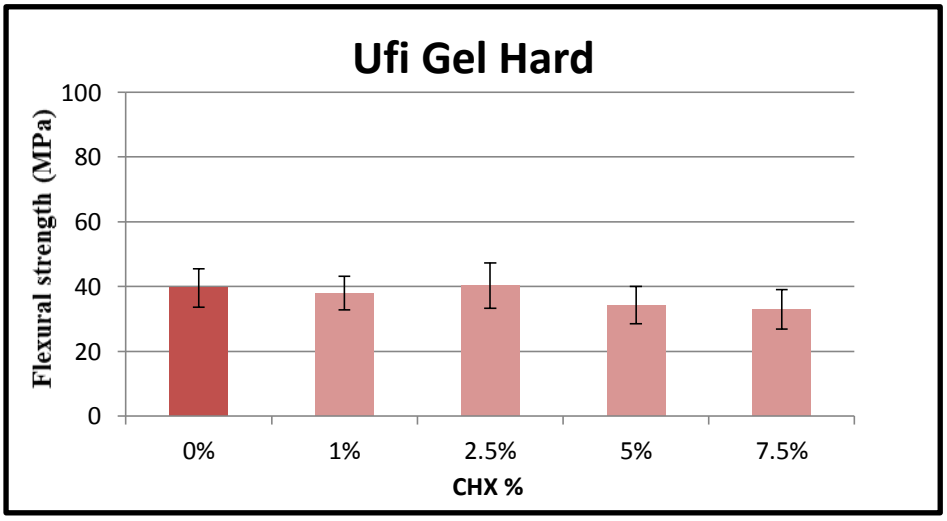

Figure 4.7 – Mean and standard deviation of values of flexural strength (MPa) of Ufi Gel Hard

Concerning Probase Cold specimens (Figure 4.8), there were differences between groups (p<0.001), caused by 7.5% CHX group that showed lower values compared to the 0% group (p=0.001) and to the 1% group (p=0.001)

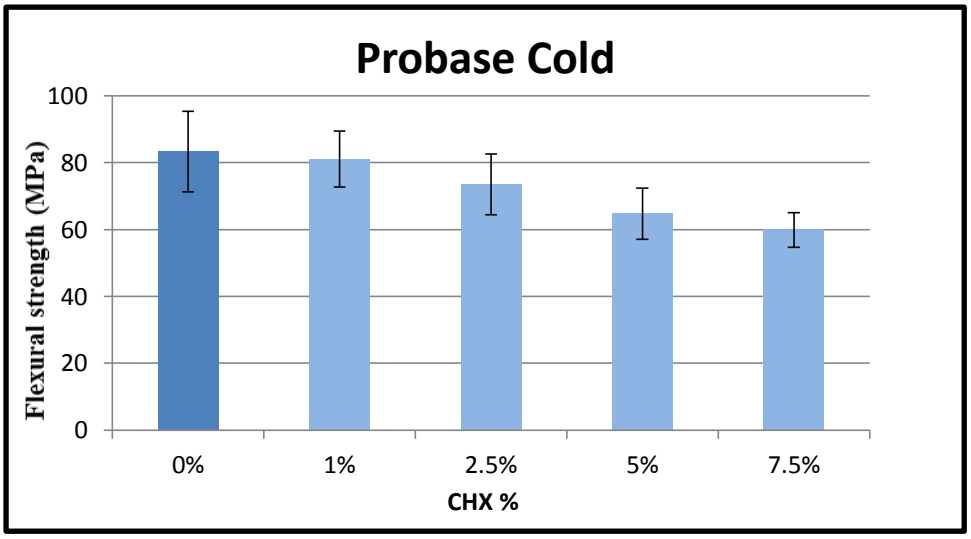

Figure 4.8 – Mean and standard deviation of values of flexural strength (MPa) of Probase Cold

5. Discussion

Due to biofilm resistance to antibacterial agents, novel strategies to overcome this problem were needed (Shi-Qiang Gong *et al*., 2012). Therefore, to avoid the proliferation of microorganisms on denture base resins and subsequent pathologic processes like denture induced stomatitis and related oral diseases, incorporating substances that could show antimicrobial activity is a widely used route intending to avoid the referred problematics and has been embodied with various studies (Addy M. and Handley R., 1981; Mirth D.B., 1989; Ahlström *et al*., 1999; Batoni G. *et al*., 2001; Etienne O. *et al*., 2005; Chávez de Paz, 2009; Li *et al.*, 2010; Darwish *et al.*, 2011; Cochis *et al.*, 2012; King G., 2012; Shinonaga *et al*., 2012; Salim *et al*., 2012b; Salim *et al*. 2012c; Salim *et al*., 2013a; Sousa C., 2014).

One simple approach to incorporate medications into removable appliances is to use them on soft liners or tissue conditioners. However, this solution implicates short-term effect and presents difficulties related to the maintenance needs of these materials (Douglas *et al*., 1973; Quinn D.M., 1985; Schneid T.R., 1992; Chow *et al*., 1999). One solution to surpass this was to incorporate antimicrobial substances on the polymers of the denture bases materials. Regarding the use of medication impregnated on the stated above materials, there are uncertainties about its effects on the mechanical properties of the acrylic resins, as research proved to exist few studies that investigated about this issue.

The mechanical effects of antimicrobial agents incorporation on acrylic resins were the objective of some studies: some evaluated peel bond strenght (Alcantara *et al.*, 2012; Salim *et al*., 2012c; Salim *et al.*, 2012d), some assessed those effects over roughness (Cunha *et al.*, 2009; Regis *et al.*, 2011), flexural strenght (Casemiro *et al.*, 2008; Cunha *et al.*, 2009; Regis *et al.*, 2011; Sodagar *et al.*, 2013; Sousa C., 2014), hardness (Addy M. and Handley R., 1981; Regis *et al.*, 2011; Martinna M.B. *et al.*, 2014; Sousa C., 2014), fracture toughness (Alaa Al-Haddad *et al*., 2014) and surface free energy (Sousa C., 2014). From the stated above, only Addy M. and Handley R. (Addy M. and Handley R., 1981), Alcantara (Alcantara *et al*., 2012), Salim (Salim *et al*., 2012c: Salim *et al*., 2012d), Alaa Al-Haddad (Alaa Al-Haddad *et al*., 2014), Martinna (Martinna M.B. *et al*., 2014) and Sousa (Sousa C., 2014) studied CHX incorporation effects on acrylic resins.

In the present study, microhardness and flexural strenght were evaluated to check the effect of chlorhexidine on the mechanical properties.

Being hardness defined as the resistance offered by a material to permanent surface indentation or penetration, it is an important feature that is present in acrylic materials used in dentures (Ali *et al*., 2008; Pinto Lde *et al*., 2010). This property of these materials provides them the ability to resist to the variable conditions present in the oral cavity environment (Tamura F. *et al*., 2002) and also permits withstanding excessive wear by denture cleansers, brushing and food (Ali *et al*., 2008). Flexural strenght is an intrinsic property of acrylic resins which has been studied and widely used to previse the behavior of these materials when subjected to repeated masticatory loads, as they are constantly on denture wearers (Haselton *et al.*, 2002; Balkenhol *et al.*, 2007; Gunjan Dhir *et al*., 2007; Ali *et al.*, 2008; Casemiro *et al.*, 2008; André G.P. *et al*., 2010). It is know that a decrease on flexural strenght of denture's base acrylic resin flexural strength can result in greater fracture incidence by impact or oclusal forces (Cunha *et al*., 2009; Sato S. *et al*., 2005).

On the present study, CHX was the pharmacological molecule incorporated to study its effects on the mechanical properties. Others studied the incorporation of substances like fluconazole, silver-zinc zeolite, fluoralkyl methacrylate, methacryloyloxyundecylpyridinium bromide or TiO_2 and SiO_2 nanoparticles) (Casemiro *et al.*, 2008; Cunha *et al.*, 2009; Regis *et al.*, 2011; Sodagar *et al.*, 2013). A large number of studies evidenced that CHX, when incorporated on acrylic resins, has a more efficient candidacidal effect in comparison to other antifungical drugs. This evidence has been shown both on releasing studies and microbiologic tests (Amin *et al*., 2009; Pusateri C.R. *et al.*, 2009; Ryalat *et al*., 2011; Salim *et al*., 2013a; Salim *et al*., 2013b).

It has been shown that once CHX is incorporated into PMMA, it retains its therapeutic dose for up to 28 days (Amin *et al*., 2009; Salim *et al*., 2012b).

Only one study by Sousa (Sousa C., 2014) that evaluated the effect of CHX incorporation on the mechanical and surface properties of acrylic reline resins after CHX has been completely eluted from these materials. On the referred study, an aging thermocycling process, corresponding to 3 months of temperature variation in the oral environment (Gale and Darvell, 1999), which can be induced by breathing, eating and drinking (Palmer *et al*., 1992), was applied. This 3 months period was chosen because there weren't found studies where had been established when CHX had completely vanished from the acrylic resin. Therefore, this time interval was considered to be an

approximation of the time after which it was expected that CHX had been completely eluted from the resin (Sousa C., 2014). The CHX concentration incorporated on the acrylic resins was 10%.

Besides evaluating the effects of the reline resins on the stated above parameters, it was also evaluated the effect of the incorporation of different concentrations of CHX by material. As stated before, all the concentrations used were inferior to 10% (0%; 1%; 2.5%; 5%; 7.5%) as Sousa (Sousa C., 2014) concluded that this concentration is prejudicial to the mechanical properties in study for the resins mentioned.

Regarding the effect of the reline resin on microhardness, the values showed differences between materials, with Probase Cold showing higher values and Kooliner the lower results, conclusion that is with previous results of Sousa (Sousa C., 2014).

Therefore, we are able to reject the first null hypothesis that the resin type doesn't influence the microhardness.

Concerning the effect of CHX incorporation on microhardness of Kooliner there were differences between groups.

The incorporation of CHX, in different concentrations, on Kooliner, regarding microhardness values, conduced to significant statistical differences, as the 1% CHX group had higher values than the 5% CHX group and the 7.5% CHX group. Despite the related differences, the various CHX concentrations introduced on Kooliner not only didn't affected the material microhardness but also may have had some benefit as the 1% concentration showed higher values as stated previously. Ufi Gel Hard specimens showed differences between groups. These differences were between 5% CHX group and 0% CHX and 1% CHX groups. The same described for Kooliner is verifiable with Ufi Gel Hard. CHX incorporation did not prejudiced the material's microhardness as the 5% CHX concentration showed even higher results than the 0% group and the 1% group, and similar to 7.5% group. Evaluating Probase Cold values of microhardness, there were no statistically significant differences between different groups with different Effects of chlorhexidine incorporation on the mechanical properties of acrylic reline resins CHX concentrations, meaning that this property of Probase Cold, on the conditions of the present study, isn't affected by CHX incorporation.

For lower values verified on the evaluated materials containing PEMA, there are different hypothetical explanations, yet they may be associated. Addy M. and Handley R. (Addy M. and Handley R., 1981) stated that particles of CHX may dissolve and result in porosity of the acrylic resin, which adding to current knowledge that CHX

elution from resins has a high initial rate during the first days after incorporation (Amin *et al*., 2009; Ryalat *et al*., 2011; Salim *et al*., 2012b) makes possible to hypothesize that when specimens were tested they presented a higher degree of porosity, what could have influence on microhardness. On the other hand, interaction between CHX molecules and PEMA and PMMA particles may be different. Alaa Al-Haddad (Alaa Al-Haddad *et al*., 2014), when studying CHX incorporation on PMMA constituted resins, hypothesized that probably CHX could interact with the polymeric matrix of cross-linking materials mitigating the bond of monomers. This probably can be verifiable for also non-crosslinking materials. Plus, depending on the size of CHX particles included on the resin, may result in various sizes voids within the material and a greater presence of voids may translate on a greater ease of the material being penetrated. As far as Probase Cold is concerned, being a PMMA constituted material, the interaction of CHX may be different and it is know that it has higher conversion rates of the monomer, so from the beginning it has less formation of pores and higher microhardness values

As stated before, lower hardness values tend to facilitate wear of acrylic resins by action of brushing, cleansers and food, getting the resin more fragile, as they all can cause significant surface deterioration. (Monsenego P., 2000; Nikawa *et al*., 2003; Brozek *et al*, 2007; Ali *et al*., 2008; Boscato *et al*., 2009; Brozek *et al*., 2009; Brozek *et al*., 2011). As Probase Cold presented higher microhardness values, it could be used as a carrier for local delivery of CHX, when employed as a reline material for the existing denture, within the oral cavity. Addy M and Handley R (Addy M. and Handley R.,1981) and Sousa (Sousa C., 2014) suggested that due to their results, when the resin is subjected to an aging process similar to what happens in oral cavity, there's probably a necessity to substitute the reline resin after some time. Adding to this, Probase Cold showed to have the lower levels of cytotoxicity of all three testes resins (Mendes de Oliveira *et al*., 2014), therefore this should be considered when choosing the relining material.

Thereby, despite the fact that these results made us reject the second null hypothesis that refers to: The microhardness isn't affected by the different concentrations of CHX incorporated, the CHX incorporation doesn't translate into negative results over the resins microhardness, which made possible to conclude that the concentrations used are harmless regarding this specific property.

In the present study, regarding the effect of the reline resin on flexural strenght, values showed differences between groups. Kooliner and Ufi gel showed similar values

but Probase Cold showed significant differences in relation to the other two resins, having higher values of flexural strenght. These differences between Kooliner, Ufi Gel Hard and Probase Cold, are consilient to Arima (Arima *et al*., 1995) and Sousa (Sousa C., 2014) when this studies state that the mechanical behavior of cross-linking and non-crosslinking materials and between this two and mainly PMMA constituted materials is different. Higher values for Probase Cold in terms of the studied parameters in comparison to the other two materials may be explained by its curing cycle at high temperature and pressure as this provides higher monomer conversion. Various authors stated that this higher conversion translates into better mechanical properties of the resin (Jagger R.G., 1978; Shibata *et al*., 2007; Urban *et al.*, 2007).

In relation to the effect of CHX incorporation on flexural strenght, Kooliner and Ufi Gel Hard didn't show significantly different values between different concentrations of CHX. Concerning Probase Cold, the flexural strenght values were different between groups.

In the present study, evaluating the effects of the reline resin on flexural strenght, results showed that Kooliner and Ufi Gel Hard had no differences between them, but both had with Probase Cold, having the latest higher flexural strenght values in relation the other two materials.

Therefore we are able to reject the third null hypothesis that expose that the resin type doesn't influence the flexural strenght, since Probase Cold showed higher results of flexural strenght values than the other two materials.

This result is consistent with that of Sousa (Sousa C., 2014) and with other studies (Gunjan Dhir *et al*., 2007; Casemiro *et al.*, 2008; Cunha *et al.*, 2009; André G.P. *et al*., 2010; Regis *et al.*, 2011; Sodagar *et al.*, 2013) which evaluated the influence of antimicrobial agents' incorporation on acrylic resin's flexural strenght, having all shown that flexural strenght is negatively influenced by compounds incorporation.

Regarding the effect of different CHX percentages incorporation on flexural strenght, on Kooliner, the results made possible to conclude that there were no statistically significant differences between different groups. These results were the same for Ufi Gel Hard groups. For this material these results are consistent with the results of Sousa (Sousa C., 2014). Probase Cold results showed that there were differences between 7.5% CHX group and 0% CHX group and 1% CHX group. These differences made possible to conclude that on Probase Cold, the incorporation of CHX below 7.5% is not prejudicial to flexural strenght.

Evaluating the above-mentioned it is possible to reject the forth null hypothesis that asks if the flexural strength is affected by different concentrations of CHX incorporated.

One possible explanation for the differences between groups on Probase Cold resides on the fact that probably the incorporation of CHX in the polymeric chain of PMMA has a similar effect to that described by Cunha *et al*. in 2009. In the cited report it is affirmed that the explanation for lower flexural strenght values of acrylic resins after incorporation of a fluoralkyl methacrilate resides in the intermolecular interaction because the presence of this substance in methacrylic polymers results on different intermolecular distances among polymers chains. Probably the polymerization process is hampered resulting on the presence of a large amount of residual monomer. As stated by Jagger (Jagger R.G., 1978) and Shibata (Shibata *et al*., 2007), this residual monomer adversely affects the mechanical properties of resins, by means of a plasticizing effect (Jagger R.G., 1978).

Several studies report that flexural strenght value decrease with the increase in antimicrobial agents added to acrylic resins (Addy M. and Handley R. *et al*., 1981; Shibata *et al*., 2007; Casemiro *et al*., 2008; Gujan Dhir *et al*., 2009; Cunha *et al*., 2009; André G.P. *et al*., 2011; Sousa C., 2014). By the sum of negative effects of acrylic resins incomplete polymerization and inherent increased amount of residual monomer, there is a possible reason for loss of mechanical properties on Probase Cold. Despite the previously mentioned, a 7.5 percentage of CHX incorporation results in flexural strenghts whose values are yet in accordance to ISO requirements, which did not happened with 10% CHX concentrations used by Sousa (Sousa C., 2014).

The present study obtained important conclusions regarding the concentrations that can be used for CHX incorporation without compromising mechanical properties.

However, as these properties aren't the only important factors determining the choice of the best material to be used as antimicrobial agent carrier, further studies are recommended to investigate the conversion degree of acrylic resins and quantify the amount of residual monomer. SEM and TEM analysis should be made in order to evaluate possible alterations on the polymeric net. Furthermore, microbiological, release and cytotoxicity tests, using CHX are also needed. All stated tests and analysis should be crossed with this and other studies results to achieve a consensus on which is the best material to serve as antimicrobial agent carrier.

6. Conclusions

Regarding the effects of different reline resins on microhardness values, the present study made possible to conclude that when comparing all three materials:

- Probase Cold showed the highest values, followed by Ufi Gel Hard and Kooliner showed the lowest values.

Concerning the effects of incorporation of different CHX concentrations on microhardness, by material:

- Kooliner and Ufi Gel Hard specimens showed scarce differences between groups of different CHX incorporated.

- Probase Cold had significant differences between any of the groups of CHX incorporated.

Regarding the effects of different reline resins on flexural strenght values, the present study made possible to conclude that when comparing all materials, the flexural strenght of:

- Probase Cold showed higher values than Kooliner and Ufi Gel Hard, which showed no differences between them.

In relation to the effects of incorporation of different CHX concentrations on flexural strenght, by material:

- Kooliner and Ufi Gel Hard specimens didn't show differences, between all groups of CHX incorporated.

- For Probase Cold specimens, the group of 7.5% showed lower values of flexural strenght that the group with no incorporation or even the 1% CHX group.

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Appendices

Appendix 1- Tables

Table 1- Mean, median, standard deviation, minimum and maximum values for microhardness (kg/mm^2)

Material	CHX concentration	*n*	Mean	Median	Standard deviation	Minimum	Maximum
Kooliner	0%	8	5.44	5.62	0.38	4.53	5.68
	1%	8	5.97	6.03	0.62	5.15	6.86
	2.5%	8	5.40	5.05	0.72	5.52	6.55
	5%	8	4.65	4.47	0.43	4.18	5.17
	7.5%	8	4.87	5.00	0.48	3.93	5.37
Ufi Gel Hard	0%	8	8.51	8.53	0.48	7.90	9.15
	1%	8	8.34	8.22	0.55	7.51	9.39
	2.5%	8	9.20	9.26	0.82	8.08	10.59
	5%	8	9.89	9.85	0.93	8.89	11.28
	7.5%	8	8.60	8.62	0.53	7.97	9.21
Probase Cold	0%	8	11.78	11.78	0.54	10.77	12.54
	1%	8	11.74	11.72	0.38	11.10	12.35
	2.5%	8	11.40	11.38	0.31	11.03	11.98
	5%	8	11.67	11.68	0.35	11.10	12.30
	7.5%	8	11.31	11.37	0.29	10.83	11.73

Table 2- Mean, median, standard deviation, minimum and maximum values for flexural strenght (MPa)

Material	CHX concentration	*n*	Mean	Median	Standard deviation	Minimum	Maximum
Kooliner	0%	8	39.92	42.07	5.44	29.58	46.04
	1%	8	41.41	41.32	2.42	38.24	45.95
	2.5%	8	38.78	40.64	4.88	2852	43.36
	5%	8	35.96	37.33	5.39	24.41	41.51
	7.5%	8	38.34	39.12	3.28	32.55	42.84
Ufi Gel Hard	0%	8	39.5338	37.04	5.99	33.38	48.21
	1%	8	37.9188	37.36	5.20	28.87	44.78
	2.5%	8	40.2013	40.07	6.99	29.15	50.50
	5%	8	34.2088	33.92	5.75	24.54	43.25
	7.5%	8	32.9125	33.61	6.11	24.20	40.16
Probase Cold	0%	8	83.34	79.18	12.05	65.90	98.08
	1%	8	81.05	83.64	8.38	68.02	89.37
	2.5%	8	73.53	71.09	9.05	60.66	88.99
	5%	8	65.01	62.51	7.68	55.05	79.50
	7.5%	8	59.85	60.26	5.18	48.75	66.38

Appendix 2- List of Tables

Appendix 3- List of figures

Apendix 4- List of abbreviations

1,6 HDMA	1,6-hexanedioldimetacrylate
CHX	Chlorhexidine diacetate monohydrate
FS	Flexural strenght
HDMA	Hexanediol dimethacrylate
IBMA	Isobutylmethacrylate
ISO	International Organization for Standardization
K	Kooliner
KHN	Knoop Hardness Number
MMA	Methylmethacrylate
MPa	Megapascal
PC	Probase Cold
PEMA	Polyethilmethacrylate
PMMA	Polymethylmethacrylate
U	Ufi Gel Hard

Appendix 5- Experimental data

Knoop hardness (Kooliner)

Indentation	KHN	Indentation	KHN	Indentation	KHN	Indentation	KHN
KA1.1	5.5	**KA4.6**	4.3	**KA7.11**	4.4	**KB3.4**	7.1
KA1.2	5.4	**KA4.7**	4.0	**KA7.12**	4.5	**KB3.5**	4.1
KA1.3	5.8	**KA4.8**	3.9	**KA8.1**	5.6	**KB3.6**	9.8
KA1.4	4.0	**KA4.9**	3.7	**KA8.2**	5.3	**KB3.7**	6.4
KA1.5	5.5	**KA4.10**	4.4	**KA8.3**	5.1	**KB3.8**	5.9
KA1.6	4.7	**KA4.11**	3.9	**KA8.4**	6.8	**KB3.9**	6.5
KA1.7	6.0	**KA4.12**	5.9	**KA8.5**	4.7	**KB3.10**	7.0
KA1.8	5.2	**KA5.1**	6.1	**KA8.6**	4.3	**KB3.11**	8.6
KA1.9	5.6	**KA5.2**	4.8	**KA8.7**	5.9	**KB3.12**	7.0
KA1.10	8.8	**KA5.3**	5.6	**KA8.8**	6.7	**KB4.1**	5.5
KA1.11	6.0	**KA5.4**	5.8	**KA8.9**	4.8	**KBh4.2**	6.4
KA1.12	5.0	**KA5.5**	5.5	**KA8.10**	4.8	**KB4.3**	5.0
KA2.1	5.1	**KA5.6**	5.2	**KA8.11**	5.7	**KB4.4**	6.0
KA2.2	5.9	**KA5.7**	5.4	**KA8.12**	5.6	**KB4.5**	6.7
KA2.3	4.8	**KA5.8**	5.3	**KB1.1**	5.4	**KB4.6**	6.5
KA2.4	7.2	**KA5.9**	5.0	**KB1.2**	4.5	**KB4.7**	6.0
KA2.5	5.3	**KA5.10**	7.7	**KB1.3**	4.1	**KB4.8**	7.2
KA2.6	5.4	**KA5.11**	6.6	**KB1.4**	6.0	**KB4.9**	5.3
KA2.7	4.4	**KA5.12**	5.2	**KB1.5**	5.6	**KB4.10**	6.7
KA2.8	6.6	**KA6.1**	5.5	**KB1.6**	4.0	**KB4.11**	7.0
KA2.9	5.3	**KA6.2**	7.2	**KB1.7**	4.9	**KB4.12**	6.8
KA2.10	6.1	**KA6.3**	5.9	**KB1.8**	5.7	**KB5.1**	5.7
KA2.11	5.5	**KA6.4**	4.7	**KB1.9**	4.2	**KB5.2**	4.8
KA2.12	5.9	**KA6.5**	7.0	**KB1.10**	5.7	**KB5.3**	6.4
KA3.1	5.1	**KA6.6**	5.1	**KB1.11**	5.2	**KB5.4**	6.1
KA3.2	4.7	**KA6.7**	6.2	**KB1.12**	6.9	**KB5.5**	5.1
KA3.3	5.3	**KA6.8**	4.9	**KB2.1**	5.4	**KB5.6**	6.0
KA3.4	5.2	**KA6.9**	6.1	**KB2.2**	5.2	**KB5.7**	6.1
KA3.5	5.0	**KA6.10**	5.2	**KB2.3**	7.3	**KB5.8**	5.5
KA3.6	5.7	**KA6.11**	4.5	**KB2.4**	5.0	**KB5.9**	5.2
KA3.7	6.8	**KA6.12**	5.4	**KB2.5**	5.5	**KB5.10**	6.5
KA.3.8	4.9	**KA7.1**	5.3	**KB2.6**	3.4	**KB5.11**	6.8
KA3.9	6.6	**KA7.2**	5.0	**KB2.7**	5.8	**KB5.12**	6.1
KA3.10	6.1	**KA7.3**	6.4	**KB2.8**	6.6	**KB6.1**	6.5
KA3.11	6.9	**KA7.4**	4.4	**KB2.9**	5.9	**KB6.2**	6.3
KA3.12	5.0	**KA7.5**	6.8	**KB2.10**	5.3	**KB6.3**	4.9
KA4.1	4.4	**KA7.6**	5.7	**KB2.11**	6.9	**KB6.4**	5.6
KA4.2	4.8	**KA7.7**	6.5	**KB2.12**	5.8	**KB6.5**	5.4
KA4.3	6.8	**KA7.8**	5.7	**KB3.1**	5.5	**KB6.6**	6.1
KA4.4	4.4	**KA7.9**	4.5	**KB3.2**	4.0	**KB6.7**	7.4
KA4.5	3.9	**KA7.10**	5.1	**KB3.3**	6.9	**KB6.8**	4.8

KB6.9	4.5	**KC2.6**	7.7	**KC6.3**	4.3	**KD1.12**	3.6
KB6.10	6.2	**KC2.7**	6.1	**KC6.4**	4.9	**KD2.1**	5.2
KB6.11	6.9	**KC2.8**	8.1	**KC6.5**	5.0	**KD2.2**	3.7
KB6.12	9.8	**KC2.9**	5.9	**KC6.6**	5.4	**KD2.3**	4.6
KB7.1	5.2	**KC2.10**	6.0	**KC6.7**	4.6	**KD2.4**	4.6
KB7.2	4.3	**KC2.11**	7.5	**KC6.8**	5.0	**KD2.5**	5.6
KB7.3	5.2	**KC2.12**	6.2	**KC6.9**	5.6	**KD2.6**	3.9
KB7.4	4.8	**KC3.1**	4.6	**KC6.10**	4.5	**KD2.7**	4.5
KB7.5	5.0	**KC3.2**	5.6	**KC6.11**	6.9	**KD2.8**	4.5
KB7.6	4.6	**KC3.3**	5.0	**KC6.12**	5.5	**KD2.9**	4.1
KB7.7	4.9	**KC3.4**	4.8	**KC7.1**	4.1	**KD2.10**	3.8
KB7.8	5.6	**KC3.5**	5.6	**KC7.2**	4.4	**KD2.11**	3.6
KB7.9	5.2	**KC3.6**	5.4	**KC7.3**	4.4	**KD2.12**	4.2
KB7.10	6.2	**KC3.7**	4.5	**KC7.4**	4.0	**KD3.1**	5.2
KB7.11	4.7	**KC3.8**	4.8	**KC7.5**	5.6	**KD3.2**	4.5
KB7.12	6.1	**KC3.9**	5.5	**KC7.6**	4.4	**KD3.3**	4.8
KB8.1	7.7	**KC3.10**	5.1	**KC7.7**	6.1	**KD3.4**	5.3
KB8.2	5.6	**KC3.11**	4.4	**KC7.8**	4.1	**KD3.5**	4.8
KB8.3	6.6	**KC3.12**	4.5	**KC7.9**	6.2	**KD3.6**	3.7
KB8.4	8.2	**KC4.1**	4.0	**KC7.10**	6.8	**KD3.7**	6.2
KB8.5	6.6	**KC4.2**	4.7	**KC7.11**	6.7	**KD3.8**	4.5
KB8.6	6.3	**KC4.3**	4.9	**KC7.12**	4.2	**KD3.9**	5.8
KB8.7	6.6	**KC4.4**	5.2	**KC8.1**	7.0	**KD3.10**	5.5
KB8.8	5.7	**KC4.5**	4.7	**KC8.2**	6.2	**KD3.11**	5.7
KB8.9	7.9	**KC4.6**	4.6	**KC8.3**	5.5	**KD3.12**	6.0
KB8.10	6.7	**KC4.7**	4.0	**KC8.4**	5.6	**KD4.1**	4.7
KB8.11	7.9	**KC4.8**	4.6	**KC8.5**	6.2	**KD4.2**	5.7
KB8.12	6.5	**KC4.9**	4.6	**KC8.6**	7.5	**KD4.3**	4.2
KC1.1	4.8	**KC4.10**	4.0	**KC8.7**	6.1	**KD4.4**	5.3
KC1.2	6.3	**KC4.11**	4.2	**KC8.8**	5.0	**KD4.5**	4.5
KC1.3	7.4	**KC4.12**	4.7	**KC8.9**	6.4	**KD4.6**	5.2
KC1.4	6.1	**KC5.1**	4.8	**KC8.10**	5.7	**KD4.7**	4.8
KC1.5	6.4	**KC5.2**	4.7	**KC8.11**	6.8	**KD4.8**	5.1
KC1.6	5.8	**KC5.3**	4.9	**KC8.12**	5.9	**KD4.9**	5.7
KC1.7	5.8	**KC5.4**	6.1	**KD1.1**	4.5	**KD4.10**	5.3
KC1.8	5.6	**KC5.5**	3.9	**KD1.2**	5.0	**KD4.11**	5.1
KC1.9	5.0	**KC5.6**	4.7	**KD1.3**	4.6	**KD4.12**	5.8
KC1.10	7.6	**KC5.7**	4.7	**KD1.4**	4.5	**KD5.1**	4.2
KC1.11	5.5	**KC5.8**	7.5	**KD1.5**	5.1	**KD5.2**	3.7
KC1.12	5.2	**KC5.9**	5.8	**KD1.6**	4.3	**KD5.3**	3.6
KC2.1	7.0	**KC5.10**	4.7	**KD1.7**	4.2	**KD5.4**	4.1
KC2.2	5.2	**KC5.11**	4.4	**KD1.8**	3.7	**KD5.5**	4.4
KC2.3	5.3	**KC5.12**	4.0	**KD1.9**	4.6	**KD5.6**	4.7
KC2.4	6.1	**KC6.1**	3.9	**KD1.10**	3.7	**KD5.7**	3.8
KC2.5	7.5	**KC6.2**	3.6	**KD1.11**	4.3	**KD5.8**	3.7

KD5.9	4.0	**KE1.6**	4.3	**KE5.3**	5.2	**KE8.12**	7.3
KD5.10	5.6	**KE1.7**	3.7	**KE5.4**	4.6		
KD5.11	5.3	**KE1.8**	5.1	**KE5.5**	6.1		
KD5.12	4.0	**KE1.9**	4.2	**KE5.6**	5.3		
KD6.1	4.4	**KE1.10**	3.6	**KE5.7**	4.4		
KD6.2	3.9	**KE1.11**	4.1	**KE5.8**	5.8		
KD6.3	4.2	**KE1.12**	3.7	**KE5.9**	6.4		
KD6.4	3.7	**KE2.1**	6.4	**KE5.10**	5.3		
KD6.5	3.6	**KE2.2**	5.1	**KE5.11**	5.1		
KD6.6	3.9	**KE2.3**	5.2	**KE5.12**	5.9		
KD6.7	4.3	**KE2.4**	5.8	**KE6.1**	4.8		
KD6.8	3.8	**KE2.5**	4.6	**KE6.2**	5.6		
KD6.9	4.2	**KE2.6**	4.7	**KE6.3**	4.3		
KD6.10	4.4	**KE2.7**	6.0	**KE6.4**	5.6		
KD6.11	4.0	**KE2.8**	5.1	**KE6.5**	5.0		
KD6.12	5.7	**KE2.9**	5.3	**KE6.6**	4.7		
KD7.1	4.2	**KE2.10**	5.4	**KE6.7**	4.9		
KD7.2	4.2	**KE2.11**	5.4	**KE6.8**	5.2		
KD7.3	3.9	**KE2.12**	4.2	**KE6.9**	5.0		
KD7.4	5.4	**KE3.1**	4.3	**KE6.10**	5.5		
KD7.5	5.1	**KE3.2**	5.5	**KE6.11**	4.3		
KD7.6	5.0	**KE3.3**	4.6	**KE6.12**	5.8		
KD7.7	4.5	**KE3.4**	4.4	**KE7.1**	5.1		
KD7.8	4.2	**KE3.5**	4.9	**KE7.2**	5.0		
KD7.9	4.5	**KE3.6**	3.8	**KE7.3**	7.5		
KD7.10	4.0	**KE3.7**	4.9	**KE7.4**	4.3		
KD7.11	4.8	**KE3.8**	5.2	**KE7.5**	5.6		
KD7.12	5.2	**KE3.9**	5.0	**KE7.6**	3.8		
KD8.1	4.9	**KE3.10**	6.0	**KE7.7**	3.6		
KD8.2	4.6	**KE3.11**	5.9	**KE7.8**	4.2		
KD8.3	5.1	**KE3.12**	4.8	**KE7.9**	6,1		
UA8.4	5.7	**KE4.1**	4.0	**KE7.10**	3.7		
KD8.5	5.4	**KE4.2**	4.5	**KE7.11**	3.6		
KD8.6	5.1	**KE4.3**	4.0	**KE7.12**	4.1		
KD8.7	5.7	**KE4.4**	4.1	**KE8.1**	5.1		
KD8.8	5.4	**KE4.5**	4.1	**KE8.2**	5.4		
KD8.9	5.1	**KE4.6**	3.9	**KE8.3**	4.9		
KD8.10	5.4	**KE4.7**	4.5	**KE8.4**	6.0		
KD8.11	5.2	**KE4.8**	5.5	**KE8.5**	4.8		
KD8.12	4.4	**KE4.9**	5.0	**KE8.6**	4.8		
KE1.1	4.0	**KE4.10**	4.8	**KE8.7**	5.3		
KE1.2	3.5	**KE4.11**	4.1	**KE8.8**	5.8		
KE1.3	3.7	**KE4.12**	5.6	**KE8.9**	5.6		
KE1.4	3.7	**KE5.1**	4.3	**KE8.10**	4.6		
KE1.5	3.5	**KE5.2**	3.9	**KE8.11**	4.8		

Knoop hardness (Ufi Gel Hard)

Indentation	KHN	Indentation	KHN	Indentation	KHN	Indentation	KHN
UA1.1	9.0	**UA4.6**	8.6	**UA7.11**	8.3	**UB3.4**	9.7
UA1.2	9.2	**UA4.7**	8.4	**UA7.12**	7.8	**UB3.5**	8.8
UA1.3	7.7	**UA4.8**	9.7	**UA8.1**	7.7	**UB3.6**	8.7
UA1.4	8.9	**UA4.9**	9.3	**UA8.2**	7.6	**UB3.7**	8.4
UA1.5	8.3	**UA4.10**	4.7	**UA8.3**	9.8	**UB3.8**	8.7
UA1.6	8.4	**UA4.11**	10.2	**UA8.4**	8.4	**UB3.9**	8.8
UA1.7	8.5	**UA4.12**	9.2	**UA8.5**	7.3	**UB3.10**	9.9
UA1.8	8.7	**UA5.1**	8.9	**UA8.6**	8.8	**UB3.11**	8.4
UA1.9	8.2	**UA5.2**	8.7	**UA8.7**	6.9	**UB3.12**	9.3
UA1.10	8.0	**UA5.3**	9.4	**UA8.8**	7.7	**UB4.1**	7.9
UA1.11	9.6	**UA5.4**	10.2	**UA8.9**	8.4	**UB4.2**	8.5
UA1.12	9.1	**UA5.5**	9.2	**UA8.10**	5.1	**UB4.3**	8.0
UA2.1	9.1	**UA5.6**	9.0	**UA8.11**	8.4	**UB4.4**	8.5
UA2.2	9.2	**UA5.7**	9.9	**UA8.12**	8.7	**UB4.5**	7.2
UA2.3	8.5	**UA5.8**	10.3	**UB1.1**	7.5	**UB4.6**	8.6
UA2.4	8.6	**UA5.9**	8.4	**UB1.2**	8.0	**UB4.7**	8.8
UA2.5	7.3	**UA5.10**	9.8	**UB1.3**	9.2	**UB4.8**	7.3
UA2.6	8.6	**UA5.11**	7.8	**UB1.4**	7.1	**UB4.9**	8.7
UA2.7	8.7	**UA5.12**	8.2	**UB1.5**	8.6	**UB4.10**	8.2
UA2.8	8.1	**UA6.1**	8.5	**UB1.6**	8.1	**UB4.11**	8.9
UA2.9	6.8	**UA6.2**	9.8	**UB1.7**	8.8	**UB4.12**	7.2
UA2.10	7.0	**UA6.3**	8.3	**UB1.8**	8.4	**UB5.1**	8.5
UA2.11	8.3	**UA6.4**	11.1	**UB1.9**	8.2	**UB5.2**	8.7
UA2.12	8.2	**UA6.5**	7.9	**UB1.10**	8.0	**UB5.3**	7.9
UA3.1	7.4	**UA6.6**	9.1	**UB1.11**	8.7	**UB5.4**	7.7
UA3.2	7.7	**UA6.7**	7.8	**UB1.12**	8.2	**UB5.5**	8.5
UA3.3	8.5	**UA6.8**	9.2	**UB2.1**	8.4	**UB5.6**	9.2
UA3.4	10.1	**UA6.9**	10.8	**UB2.2**	8.2	**UB5.7**	8.1
UA3.5	7.7	**UA6.10**	7.6	**UB2.3**	8.0	**UB5.8**	8.6
UA3.6	9.0	**UA6.11**	8.1	**UB2.4**	8.3	**UB5.9**	9.4
UA3.7	8.5	**UA6.12**	8.1	**UB2.5**	8.4	**UB5.10**	5.5
UA3.8	8.4	**UA7.1**	7.5	**UB2.6**	8.8	**UB5.11**	8.4
UA3.9	8.6	**UA7.2**	7.8	**UB2.7**	8.4	**UB5.12**	8.0
UA3.10	8.9	**UA7.3**	7.7	**UB2.8**	8.6	**UB6.1**	8.3
UA3.11	8.2	**UA7.4**	7.0	**UB2.9**	8.1	**UB6.2**	8.2
UA3.12	8.0	**UA7.5**	8.5	**UB2.10**	7.7	**UB6.3**	8.5
UA4.1	9.9	**UA7.6**	7.8	**UB2.11**	7.9	**UB6.4**	7.1
UA4.2	9.2	**UA7.7**	7.7	**UB2.12**	8.2	**UB6.5**	8.3
UA4.3	9.0	**UA7.8**	8.9	**UB3.1**	8.1	**UB6.6**	8.1
UA4.4	9.7	**UA7.9**	8.4	**UB3.2**	8.7	**UB6.7**	7.7
UA4.5	9.7	**UA7.10**	7.6	**UB3.3**	7.8	**UB6.8**	8.0

UC6.9	8.9	**UC2.6**	10.2	**UC6.3**	8.1	**UD1.12**	9.0
UC6.10	8.2	**UC2.7**	10.9	**UC6.4**	9.2	**UD2.1**	12.4
UC6.11	8.3	**UC2.8**	11.1	**UC6.5**	9.9	**UD2.2**	10.6
UC6.12	8.5	**UC2.9**	12.2	**UC6.6**	9.9	**UD2.3**	11.8
UC7.1	8.2	**UC2.10**	10.3	**UC6.7**	10.4	**UD2.4**	10.4
UC7.2	9.2	**UC2.11**	11.5	**UC6.8**	8.5	**UD2.5**	12.2
UC7.3	8.9	**UC2.12**	11.8	**UC6.9**	10.6	**UD2.6**	11.4
UC7.4	10.8	**UC3.1**	7.5	**UC6.10**	8.5	**UD2.7**	11.8
UC7.5	9.5	**UC3.2**	7.8	**UC6.11**	7.5	**UD2.8**	11.9
UC7.6	10.1	**UC3.3**	8.9	**UC6.12**	7.6	**UD2.9**	11.4
UC7.7	9.1	**UC3.4**	8.7	**UC7.1**	9.2	**UD2.10**	10.8
UC7.8	11.8	**UC3.5**	8.4	**UC7.2**	8.6	**UD2.11**	9.7
UC7.9	8.4	**UC3.6**	8.3	**UC7.3**	8.2	**UD2.12**	10.9
UC7.10	8.8	**UC3.7**	8.4	**UC7.4**	7.4	**UD3.1**	9.3
UC7.11	8.2	**UC3.8**	7.4	**UC7.5**	8.4	**UD3.2**	8.8
UC7.12	9.7	**UC3.9**	9.2	**UC7.6**	7.3	**UD3.3**	8.1
UC8.1	7.9	**UC3.10**	8.0	**UC7.7**	7.5	**UD3.4**	8.8
UC8.2	7.3	**UC3.11**	7.8	**UC7.8**	9.4	**UD3.5**	8.7
UC8.3	7.7	**UC3.12**	8.9	**UC7.9**	7.6	**UD3.6**	9.7
UC8.4	7.0	**UC4.1**	9.3	**UD7.10**	7.0	**UD3.7**	8.8
UC8.5	8.7	**UC4.2**	7.8	**UC7.11**	7.1	**UD3.8**	9.1
UC8.6	6.5	**UC4.3**	8.5	**UC7.12**	9.3	**UD3.9**	9.8
UC8.7	7.6	**UC4.4**	8.8	**UC8.1**	8.7	**UD3.10**	9.2
UC8.8	7.6	**UC4.5**	7.8	**UC8.2**	8.1	**UD3.11**	9.0
UC8.9	7.5	**UC4.6**	10.5	**UC8.3**	8.2	**UD3.12**	7.7
UC8.10	7.2	**UC4.7**	9.4	**UC8.4**	8.5	**UD4.1**	9.6
UC8.11	7.0	**UC4.8**	11.7	**UC8.5**	11.0	**UD4.2**	10.3
UC8.12	8.1	**UC4.9**	11.4	**UC8.6**	10.8	**UD4.3**	10.3
UC1.1	8.5	**UC4.10**	8.4	**UC8.7**	10.8	**UD4.4**	10.9
UC1.2	11.1	**UC4.11**	9.0	**UC8.8**	9.9	**UD4.5**	9.5
UC1.3	12.6	**UC4.12**	11.1	**UC8.9**	9.9	**UD4.6**	11.4
UC1.4	10.5	**UC5.1**	9.5	**UC8.10**	7.0	**UD4.7**	11.5
UC1.5	10.4	**UC5.2**	9.0	**UC8.11**	8.7	**UD4.8**	10.8
UC1.6	10.7	**UC5.3**	9.1	**UC8.12**	8.8	**UD4.9**	9.2
UC1.7	11.1	**UC5.4**	10.9	**UD1.1**	9.1	**UD4.10**	9.0
UC1.8	9.8	**UC5.5**	7.8	**UD1.2**	9.4	**UD4.11**	10.1
UC1.9	10.3	**UC5.6**	8.7	**UD1.3**	9.0	**UD4.12**	10.4
UC1.10	11.8	**UC5.7**	10.0	**UD1.4**	10.3	**UD5.1**	9.2
UC1.11	11.0	**UC5.8**	9.4	**UD1.5**	9.4	**UD5.2**	11.4
UC1.12	9.3	**UC5.9**	10.5	**UD1.6**	8.8	**UD5.3**	10.4
UC2.1	8.2	**UC5.10**	8.0	**UD1.7**	9.0	**UD5.4**	10.5
UC2.2	7.0	**UC5.11**	11.3	**UD1.8**	9.9	**UD5.5**	9.9
UC2.3	7.6	**UC5.12**	7.6	**UD1.9**	7.5	**UD5.6**	9.6
UC2.4	8.1	**UC6.1**	7.3	**UD1.10**	9.0	**UD5.7**	9.1
UC2.5	9.3	**UC6.2**	8.2	**UD1.11**	8.8	**UD5.8**	10.6

UD5.9	10.5	**UE1.6**	8.9	**UE5.3**	7.8	**UE8.12**	8.7
UD5.10	10.8	**UE1.7**	9.2	**UE5.4**	8.4		
UD5.11	9.9	**UE1.8**	8.1	**UE5.5**	8.9		
UD5.12	9.1	**UE1.9**	8.6	**UE5.6**	7.9		
UD6.1	11.0	**UE1.10**	9.1	**UE5.7**	6.7		
UD6.2	9.8	**UE1.11**	9.5	**UE5.8**	8.1		
UD6.3	11.9	**UE1.12**	7.8	**UE5.9**	8.5		
UD6.4	9.1	**UE2.1**	8.4	**UE5.10**	8.4		
UD6.5	11.8	**UE2.2**	9.6	**UE5.11**	8.2		
UD6.6	11.5	**UE2.3**	8.8	**UE5.12**	8.2		
UD6.7	12.0	**UE2.4**	8.7	**UE6.1**	8.6		
UD6.8	11.1	**UE2.5**	7.8	**UE6.2**	8.8		
UD6.9	11.2	**UE2.6**	9.6	**UE6.3**	7.9		
UD6.10	10.9	**UE2.7**	11.4	**UE6.4**	9.8		
UD6.11	10.8	**UE2.8**	8.8	**UE6.5**	9.0		
UD6.12	11.0	**UE2.9**	10.1	**UE6.6**	8.8		
UD7.1	9.1	**UE2.10**	7.9	**UE6.7**	8.4		
UD7.2	8.5	**UE2.11**	10.7	**UE6.8**	8.0		
UD7.3	8.4	**UE2.12**	8.6	**UE6.9**	7.4		
UD7.4	8.1	**UE3.1**	9.0	**UE6.10**	8.3		
UD7.5	8.4	**UE3.2**	8.5	**UE6.11**	8.8		
UD7.6	8.6	**UE3.3**	8.7	**UE6.12**	7.9		
UD7.7	9.1	**UE3.4**	8.6	**UE7.1**	8.4		
UD7.8	9.4	**UE3.5**	8.4	**UE7.2**	8.6		
UD7.9	8.6	**UE3.6**	9.0	**UE7.3**	8.8		
UD.10	10.0	**UE3.7**	7.8	**UE7.4**	8.7		
UD7.11	9.7	**UE3.8**	8.7	**UE7.5**	7.8		
UD7.12	8.8	**UE3.9**	9.0	**UE7.6**	8.3		
UD8.1	10.3	**UE3.10**	8.8	**UE7.7**	7.2		
UD8.2	7.4	**UE3.11**	9.0	**UE7.8**	5.7		
UD8.3	9.2	**UE3.12**	9.6	**UE7.9**	7.7		
UD8.4	10.2	**UE4.1**	8.2	**UE7.10**	7.8		
UD8.5	9.0	**UE4.2**	5.3	**UE7.11**	8.7		
UD8.6	7.9	**UE4.3**	9.1	**UE7.12**	8.7		
UD8.7	10.8	**UE4.4**	8.6	**UE8.1**	9.1		
UD8.8	12.5	**UE4.5**	7.6	**UE8.2**	8.7		
UD8.9	9.1	**UE4.6**	7.8	**UE8.3**	7.8		
UD8.10	9.7	**UE4.7**	8.2	**UE8.4**	8.6		
UD8.11	10.7	**UE4.8**	7.9	**UE8.5**	9.8		
UD8.12	8.5	**UE4.9**	8.3	**UE8.6**	8.4		
UE1.1	7.6	**UE4.10**	8.2	**UE8.7**	11.0		
UE1.2	10.4	**UE4.11**	7.7	**UE8.8**	9.2		
UE1.3	8.6	**UE4.12**	8.7	**UE8.9**	11.0		
UE1.4	11.4	**UE5.1**	7.7	**UE8.10**	9.0		
UE1.5	9.8	**UE5.2**	8.2	**UE8.11**	9.2		

Knoop hardness (Probase Cold)

Indentation	KHN	Indentation	KHN	Indentation	KHN	Indentation	KHN
PA1.1	10.0	**PA4.6**	11.4	**PA7.11**	12.1	**PB3.4**	12.2
PA1.2	11.2	**PA4.7**	13.9	**PA7.12**	11.0	**PB3.5**	10.3
PA1.3	11.2	**PA4.8**	13.2	**PA8.1**	10.8	**PB3.6**	14.7
PA1.4	11.8	**PA4.9**	11.4	**PA8.2**	10.4	**PB3.7**	13.1
PA1.5	11.1	**PA4.10**	13.1	**PA8.3**	10.7	**PB3.8**	11.3
PA1.6	11.3	**PA4.11**	12.7	**PA8.4**	10.8	**PB3.9**	11.1
PA1.7	13.0	**PA4.12**	13.0	**PA8.5**	10.6	**PB3.10**	12.0
PA1.8	10.4	**PA5.1**	11.4	**PA8.6**	10.5	**PB3.11**	11.5
PA1.9	11.3	**PA5.2**	11.1	**PA8.7**	10.3	**PB3.12**	10.2
PA1.10	11.7	**PA5.3**	11.7	**PA8.8**	10.6	**PB4.1**	11.7
PA1.11	11.8	**PA5.4**	12.4	**PA8.9**	10.8	**PB4.2**	10.7
PA1.12	12.5	**PA5.5**	12.0	**PA8.10**	11.4	**PB4.3**	9.0
PA2.1	11.6	**PA5.6**	10.9	**PA8.11**	11.2	**PB4.4**	14.2
PA2.2	11.2	**PA5.7**	13.6	**PA8.12**	11.1	**PB4.5**	11.3
PA2.3	11.3	**PA5.8**	11.5	**PB1.1**	12.0	**PB4.6**	12.5
PA2.4	11.0	**PA5.9**	11.4	**PB1.2**	13.6	**PB4.7**	12.3
PA2.5	11.8	**PA5.10**	12.1	**PB1.3**	12.7	**PB4.8**	16.0
PA2.6	11.4	**PA5.11**	14.6	**PB1.4**	11.8	**PB4.9**	13.1
PA2.7	11.7	**PA5.12**	13.0	**PB1.5**	12.1	**PB4.10**	12.5
PA2.8	12.5	**PA6.1**	12.4	**PB1.6**	11.7	**PB4.11**	12.1
PA2.9	12.3	**PA6.2**	12.0	**PB1.7**	10.0	**PB4.12**	12.8
PA2.10	13.2	**PA6.3**	11.5	**PB1.8**	11.2	**PB5.1**	10.9
PA2.11	11.3	**PA6.4**	12.6	**PB1.9**	12.1	**PB5.2**	12.0
PA2.12	10.2	**PA6.5**	11.7	**PB1.10**	12.3	**PB5.3**	12.9
PA3.1	11.8	**PA6.6**	11.6	**PB1.11**	11.2	**PB5.4**	12.1
PA3.2	11.7	**PA6.7**	12.0	**BP1.12**	13.6	**PB5.5**	11.1
PA3.3	11.5	**PA6.8**	9.9	**PB2.1**	10.9	**PB5.6**	10.4
PA3.4	12.4	**PA6.9**	13.3	**PB2.2**	11.3	**PB5.7**	11.0
PA3.5	11.5	**PA6.10**	11.3	**PB2.3**	10.2	**PB5.8**	11.8
PA3.6	11.8	**PA6.11**	11.6	**PB2.4**	11.8	**PB5.9**	11.2
PA3.7	10.0	**PA6.12**	13.2	**PB2.5**	11.9	**PB5.10**	11.3
PA3.8	11.0	**PA7.1**	12.1	**PB2.6**	12.5	**PB5.11**	11.6
PA3.9	11.5	**PA7.2**	11.5	**PB2.7**	14.0	**PB5.12**	12.1
PA3.10	11.0	**PA7.3**	12.2	**PB2.8**	11.5	**PB6.1**	11.0
PA3.11	12.1	**PA7.4**	11.7	**PB2.9**	13.3	**PB6.2**	11.8
PA3.12	13.2	**PA7.5**	13.1	**PB2.10**	10.8	**PB6.3**	10.9
PA4.1	11.4	**PA7.6**	13.4	**PB2.11**	12.0	**PB6.4**	12.5
PA4.2	13.6	**PA7.7**	12.6	**PB2.12**	13.6	**PB6.5**	12.2
PA4.3	12.6	**PA7.8**	12.1	**PB3.1**	11.3	**PB6.6**	13.1
PA4.4	11.7	**PA7.9**	12.2	**PB3.2**	11.5	**PB6.7**	11.8
PA4.5	12.5	**PA7.10**	12.1	**PB3.3**	11.7	**PB6.8**	10.2

PB6.9	10.5	**PC2.6**	12.7	**PC6.3**	11.4	**PD1.12**	11.1
PB6.10	10.7	**PC2.7**	11.7	**PC6.4**	11.1	**PD2.1**	11.5
PB6.11	11.4	**PC2.8**	10.9	**PC6.5**	11.4	**PD2.2**	9.9
PB6.12	11.8	**PC2.9**	12.0	**PC6.6**	11.8	**PD2.3**	11.4
PB7.1	10.9	**PC2.10**	11.4	**PC6.7**	11.9	**PD2.4**	10.9
PB7.2	11.7	**PC2.11**	11.1	**PC6.8**	11.5	**PD2.5**	11.1
PB7.3	11.9	**PC2.12**	12.6	**PC6.9**	10.9	**PD2.6**	10.8
PB7.4	12.1	**PC3.1**	12.5	**PC6.10**	10.7	**PD2.7**	12.0
PB7.5	11.8	**PC3.2**	13.5	**PC6.11**	12.9	**PD2.8**	11.2
PB7.6	11.0	**PC3.3**	11.8	**PC6.12**	10.9	**PD2.9**	10.1
PB7.7	11.3	**PC3.4**	10.7	**PC7.1**	12.0	**PD2.10**	11.4
PB7.8	12.2	**PC3.5**	11.8	**PC7.2**	11.0	**PD2.11**	11.5
PB7.9	11.5	**PC3.6**	12.2	**PC7.3**	10.7	**PD2.12**	11.4
PB7.10	12.0	**PC3.7**	11.8	**PC7.4**	11.1	**PD3.1**	11.0
PB7.11	12.9	**PC3.8**	11.5	**PC7.5**	12.0	**PD3.2**	10.8
PB7.12	11.1	**PC3.9**	11.9	**PC7.6**	11.7	**PD3.3**	10.3
PB8.1	12.1	**PC3.10**	12.3	**PC7.7**	10.9	**PD3.4**	11.4
PB8.2	11.0	**PC3.11**	11.5	**PC7.8**	10.7	**PD3.5**	12.3
PB8.3	10.6	**PC3.12**	12.3	**PC7.9**	11.6	**PD3.6**	11.8
PB8.4	10.7	**PC4.1**	12.1	**PC7.10**	107	**PD3.7**	11.4
PB8.5	11.6	**PC4.2**	11.7	**PC7.11**	12,1	**PD3.8**	10.8
PB8.6	11.0	**PC4.3**	11.6	**PC7.12**	11.8	**PD3.9**	11.9
PB8.7	10.6	**PC4.4**	13.7	**PC8.1**	11.6	**PD3.10**	11.6
PB8.8	11.2	**PC4.5**	10.4	**PC8.2**	11.3	**PD3.11**	11.1
PB8.9	10.8	**PC4.6**	11.5	**PC8.3**	11.4	**PD3.12**	12.3
PB8.10	11.0	**PC4.7**	11.1	**PC8.4**	11.1	**PD4.1**	13.4
PB8.11	11.7	**PC4.8**	11.0	**PC8.5**	11.5	**PD4.2**	12.6
PB8.12	10.9	**PC4.9**	9.9	**PC8.6**	10.3	**PD4.3**	11.7
PC1.1	11.1	**PC4.10**	10.5	**PC8.7**	11.4	**PD4.4**	11.3
PC1.2	11.0	**PC4.11**	11.4	**PC8.8**	11.3	**PD4.5**	12.0
PC1.3	10.7	**PC4.12**	11.8	**PC8.9**	11.9	**PD4.6**	11.3
PC1.4	11.7	**PC5.1**	12.3	**PC8.10**	10.6	**PD4.7**	11.3
PC1.5	12.0	**PC5.2**	10.7	**PC8.11**	10.3	**PD4.8**	10.8
PC1.6	10.1	**PC5.3**	10.9	**PC8.12**	10.9	**PD4.9**	12.4
PC1.7	11.7	**PC5.4**	10.2	**PD1.1**	11.8	**PD4.10**	10.5
PC1.8	11.0	**PC5.5**	11.3	**PD1.2**	14.0	**PD4.11**	11.5
PC1.9	11.8	**PC5.6**	10.9	**PD1.3**	11.5	**PD4.12**	11.4
PC1.10	12.5	**PC5.7**	11.2	**PD1.4**	11.6	**PD5.1**	11.3
PC1.11	11.4	**PC5.8**	11.4	**PD1.5**	10.5	**PD5.2**	11.5
PC1.12	11.7	**PC5.9**	11.0	**PD1.6**	10.1	**PD5.3**	12.3
PC2.1	12.5	**PC5.10**	10.6	**PD1.7**	13.0	**PD5.4**	13.4
PC2.2	11.0	**PC5.11**	10.3	**PD1.8**	10.9	**PD5.5**	11.5
PC2.3	11.8	**PC5.12**	11.5	**PD1.9**	11.7	**PD5.6**	11.4
PC2.4	11.6	**PC6.1**	10.3	**PD1.10**	10.8	**PD5.7**	12.0
PC2.5	11.1	**PC6.2**	10.0	**PD1.11**	12.0	**PD5.8**	11.1

PD5.9	11.3	**PE1.6**	10.7	**PE5.3**	12.0	**PE8.12**	12.3
PD5.10	12.0	**PE1.7**	11.0	**PE5.4**	12.5		
PD5.11	10.8	**PE1.8**	10.8	**PE5.5**	10.8		
PD5.12	11.5	**PE1.9**	11.7	**PE5.6**	10.8		
PD6.1	12.4	**PE1.10**	12.1	**PE5.7**	10.9		
PD6.2	12.0	**PE1.11**	11.8	**PE5.8**	11.6		
PD6.3	11.5	**PE1.12**	12.6	**PE5.9**	10.9		
PD6.4	11.0	**PE2.1**	10.7	**PE5.10**	9.9		
PD6.5	10.4	**PE2.2**	11.7	**PE5.11**	12.6		
PD6.6	11.7	**PE2.3**	11.0	**PE5.12**	12.7		
PD6.7	11.4	**PE2.4**	11.1	**PE6.1**	11.4		
PD6.8	13.4	**PE2.5**	12.2	**PE6.2**	12.1		
PD6.9	11.7	**PE2.6**	10.9	**PE6.3**	11.0		
PD6.10	10.9	**PE2.7**	11.3	**PE6.4**	12.7		
PD6.11	12.6	**PE2.8**	12.1	**PE6.5**	11.3		
PD6.12	11.8	**PE2.9**	10.6	**PE6.6**	11.0		
PD7.1	11.9	**PE2.10**	12.3	**PE6.7**	10.8		
PD7.2	12.9	**PE2.11**	10.3	**PE6.8**	10.8		
PD7.3	12.3	**PE2.12**	10.7	**PE6.9**	11.6		
PD7.4	12.1	**PE3.1**	11.6	**PE6.10**	10.8		
PD7.5	12.5	**PE3.2**	10.5	**PE6.11**	11.4		
PD7.6	13.4	**PE3.3**	11.9	**PE6.12**	11.3		
PD7.7	12.7	**PE3.4**	12.5	**PE7.1**	9.2		
PD7.8	11.8	**PE3.5**	10.8	**PE7.2**	10.1		
PD7.9	12.2	**PE3.6**	12.7	**PE7.3**	11.8		
PD7.10	11.0	**PE3.7**	11.5	**PE7.4**	10.9		
PD7.11	12.5	**PE3.8**	10.3	**PE7.5**	11.2		
PD7.12	12.3	**PE3.9**	11.3	**PE7.6**	11.8		
PD8.1	13.2	**PE3.10**	10.6	**PE7.7**	11.5		
PD8.2	11.5	**PE3.11**	12.0	**PE7.8**	11.0		
PD8.3	11.3	**PE3.12**	12.4	**PE7.9**	9.9		
PD8.4	10.9	**PE4.1**	9.9	**PE7.10**	10.7		
PD8.5	11.4	**PE4.2**	11.5	**PE7.11**	11.1		
PD8.6	13.3	**PE4.3**	11.8	**PE7.12**	10.8		
PD8.7	12.0	**PE4.4**	10.1	**PE8.1**	12.2		
PD8.8	12.3	**PE4.5**	10.4	**PE8.2**	10.6		
PD8.9	10.8	**PE4.6**	11.4	**PE8.3**	11.8		
PD8.10	11.3	**PE4.7**	11.8	**PE8.4**	12.3		
PD8.11	11.7	**PE4.8**	11.1	**PE8.5**	10.8		
PD8.12	12.7	**PE4.9**	10.6	**PE8.6**	10.4		
PE1.1	10.7	**PE4.10**	11.6	**PE8.7**	11.2		
PE1.2	11.9	**PE4.11**	11.1	**PE8.8**	12.9		
PE1.3	12.8	**PE4.12**	10.7	**PE8.9**	11.7		
PE1.4	10.8	**PE5.1**	11.0	**PE8.10**	12.5		
PE1.5	10.7	**PE5.2**	10.9	**PE8.11**	12.1		

Flexural strenght (Kooliner)

Specimen	Load at Yield (kN)	Width (mm)	Thickness (mm)	Flexural Strength (MPa)
KA1	0.0539	10.14	3.08	41.94
KA2	0.0579	10.08	3.15	43.50
KA3	0.0554	9.93	3.15	42.25
KA4	0.0380	9.96	3.11	29.58
KA5	0.0553	10.08	3.12	42.19
KA6	0.0524	9.95	3.15	39.88
KA7	0.0446	10.04	3.13	34.01
KA8	0.0784	10.06	3.56	46.04
KB1	0.0540	10.08	3.14	40.75
KB2	0.0607	10.17	3.22	43.17
KB3	0.0550	10.03	3,22	39.67
KB4	0.0599	9.98	3.13	45.95
KB5	0.0548	9.93	3.29	38.24
KB6	0.0553	9.98	3.15	41.88
KB7	0.0587	9.98	3.24	42.02
KB8	0.0575	10.12	3.28	39.61
KC1	0.0523	10.00	3.08	41.27
KC2	0.0576	10.06	3.15	43.36
KC3	0.0542	10.00	3.15	41.05
KC4	0.0546	10.90	3.11	38.84
KC5	0.0522	9.98	3.12	40.22
KC6	0.0460	10.01	3.14	34.80
KC7	0.0555	10.08	3.13	42.15
KC8	0.0488	10.11	3.56	28.52
KD1	0.0496	9.96	3.14	37.88
KD2	0.0539	10.02	3.22	38.91
KD3	0.0579	10.09	3.22	41.51
KD4	0.0524	10.00	3.13	40.11
KD5	0.0483	10.07	3.29	33.23
KD6	0.0491	10.09	3.15	36.78
KD7	0.0341	9.98	3.24	24.41
KD8	0.0497	9.95	3.28	34.82
KE1	0.0531	10.12	3.14	39.91
KE2	0.0566	10.07	3.22	40.66
KE3	0.0597	10.08	3.22	42.84
KE4	0.0501	10.01	3.13	38.32
KE5	0.0474	10.09	3.29	32.55
KE6	0.0530	9.97	3.15	40.18
KE7	0.0501	10.05	3.24	35.62
KE8	0.0525	9.98	3.28	36.67

Flexural strenght (Ufi Gel Hard)

Specimen	Load at Yield (kN)	Width (mm)	Thickness (mm)	Flexural Strength (MPa)
UA1	0.0439	10.00	3.14	33.38
UA2	0.0525	10.07	3.22	37.70
UA3	0.0665	10.00	3.22	48.21
UA4	0.0475	10.00	3.13	36.37
UA5	0.0697	10.07	3.29	47.95
UA6	0.0455	10.03	3.15	34.29
UA7	0.0499	10.04	3.24	35.52
UA8	0.0617	10.04	3.28	42.85
UB1	0.0478	10.00	3.14	36.36
UB2	0.0481	9.96	3.22	34.93
UB3	0.0570	10.09	3.22	40.86
UB4	0.0505	10.08	3.13	38.35
UB5	0.0420	10.08	3.29	28.87
UB6	0.0583	10.07	3.15	43.76
UB7	0.0623	9.94	3.24	44.78
UB8	0.0514	10.11	3.28	35.44
UC1	0.0616	10.063	3.14	46.56
UC2	0.0477	9.980	3.21	34.79
UC3	0.0533	10.027	3.20	38.93
UC4	0.0552	9.997	3.17	41.21
UC5	0.0583	9.96	3.13	44.80
UC6	0.0473	10.02	3.15	35.67
UC7	0.0396	10.01	3.19	29.15
UC8	0.0677	9.94	3.18	50.50
UD1	0.0458	9.97	3.14	34.94
UD2	0.034	10.02	3.22	24.54
UD3	0.0475	10.00	3.22	34.36
UD4	0.0570	10.09	3.13	43.25
UD5	0.0483	10.00	3.29	33.47
UD6	0.0423	10.08	3.15	31.72
UD7	0.0432	9.97	3.24	30.96
UD8	0.0588	10.14	3.28	40.43
UE1	0.0465	10.15	3.19	33.77
UE2	0.0336	10.17	3.20	24.20
UE3	0.0478	10.21	3.24	33.45
UE4	0.0332	10.09	3.17	24.56
UE5	0.0416	10.12	3.15	31.07
UE6	0.0549	10.23	3.18	39.80
UE7	0.0561	10.36	3.18	40.16
UE8	0.0482	10.04	3.15	36.29

Flexural strenght (Probase Cold)

Specimen	Load at Yield (kN)	Width (mm)	Thickness (mm)	Flexural Strength (MPa)
PA1	0.1351	9.68	3.32	94.97
PA2	0.0987	9.95	3.18	73.57
PA3	0.1149	10.22	3.26	79.34
PA4	0.1073	10.11	3.19	78.22
PA5	0.0911	10.00	3.22	65.90
PA6	0.1382	9.99	3.26	97.63
PA7	0.1082	10.22	3.17	79.02
PA8	0.1326	9.84	3.21	98.08
PB1	0.1169	9.95	3.14	89.37
PB2	0.1076	10.22	3.22	76.16
PB3	0.1220	10.12	3.22	87.20
PB4	0.1194	10.25	3.13	89.18
PB5	0.1215	10.39	3.29	81.03
PB6	0.1165	10.21	3.15	86.25
PB7	0.0952	10.00	3.24	68.02
PB8	0.1042	10.21	3.28	71.15
PC1	0.1164	9.95	3.14	88.99
PC2	0.0954	10.22	3.22	67.52
PC3	0.0957	10.12	3.22	68.40
PC4	0.0972	10.25	3.13	72.60
PC5	0.1205	10.39	3.29	80.36
PC6	0.1082	10.21	3.15	80.10
PC7	0.0849	10.00	3.24	60.66
PC8	0.1019	10.21	3.28	69.58
PD1	0.1125	10.11	3.24	79.50
PD2	0.0900	9.97	3.28	62.93
PD3	0.0776	10.26	3.21	55.05
PD4	0.0881	10.33	3.21	62.08
PD5	0.0828	10.03	3.20	60.46
PD6	0.0953	10.17	3.28	65.33
PD7	0.1050	10.12	3.27	72.77
PD8	0.0868	10.01	3.24	61.95
PE1	0.0806	10.00	3.21	58.67
PE2	0.0905	10.41	3.19	64.07
PE3	0.0813	10.05	3.20	59.25
PE4	0.0869	10.02	3.26	61.20
PE5	0.0630	10.02	3.11	48.75
PE6	0.0930	10.01	3.24	66.38
PE7	0.0846	10.06	3.23	60.45
PE8	0.0817	9.84	3.22	60.06